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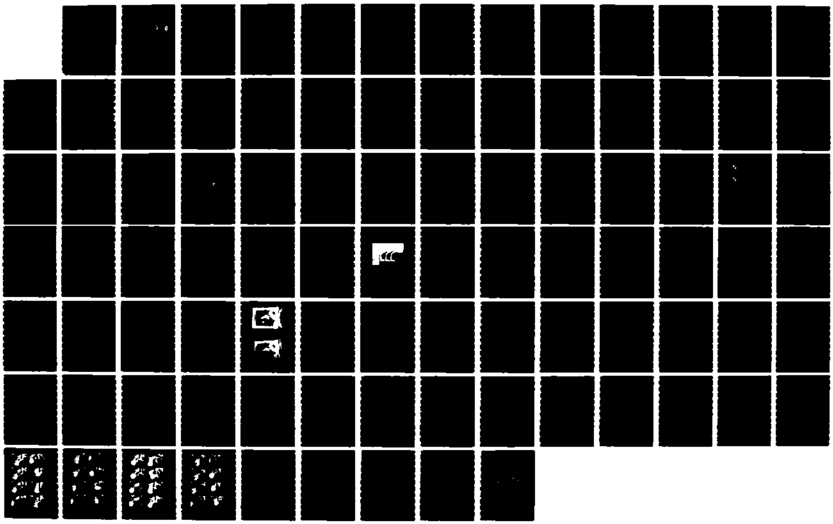

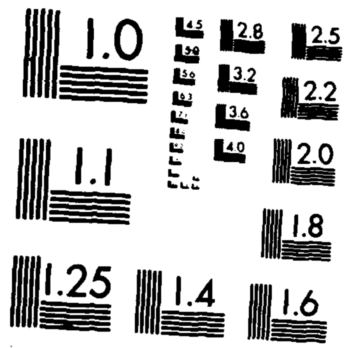

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USAAVSCOM TR-86-D-5

US ARMY
AVIATION
SYSTEMS COMMAND

DELETHALIZED CYCLIC CONTROL STICK

C. N. Whitaker, R. E. Zimmerman

SIMULA INC.
10016 S. 51st Street
Phoenix, Ariz. 85044

July 1986

Final Report for Period September 1984 - July 1986

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distribution unlimited.

Prepared for

AVIATION APPLIED TECHNOLOGY DIRECTORATE
US ARMY AVIATION RESEARCH AND TECHNOLOGY ACTIVITY (AVSCOM)
Fort Eustis, VA. 23604-5577

AVSCOM — PROVIDING LEADERS THE DECISIVE EDGE

AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

This report documents the second of two research efforts by the Aviation Applied Technology Directorate (AVSCOM) to design and test a helicopter cyclic control stick capable of separating near the floor when struck vertically during a crash. This delethalizing of the occupant's strike envelope is especially important now, as the Army is fielding it's latest helicopters (currently the UH-60A and the AH-64) equipped with crash-load-attenuating crewseats. These seats have the capability of stroking vertically as much as 17 inches during the crash sequence to absorb energy, bringing the occupant's head much closer to the cyclic stick hazard than was previously the case with the older nonstroking crewseats. This program further reduced the stick dynamic separation loads and performed full-scale seat/dummy impact tests not performed under the previous effort. The report documents a viable concept for delethalizing the cyclic stick with potential retrofit application to existing aircraft. These findings will be combined with other ongoing cockpit delethalization efforts with the goal of providing increased crash protection levels to Army aviators.

Mr. Kent F. Smith of the Aeronautical Systems Division served as Project Engineer for this program.

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In November 1983, the final report for the initial crashworthy cyclic control stick effort was published. The report detailed the development and testing of a purely mechanical self-contained crashworthy cyclic control stick equipped with load limiting and separating joint. The joint was intended to limit impact loads transmitted to a crewmember.

This report covers the additional development and testing of this concept by Simula Inc. to further delethalize the separating crashworthy cyclic control stick. Using an impact load-limiting grip pad and reduction of the moving mass to reduce the inertial forces, two configurations were subjected to static and dynamic pendulum testing. Additional destructive static testing was performed on both configurations, and one design was selected and tested in a full-scale dynamic test using an anthropomorphic dummy and a vertically stroking UH-60A Black Hawk crewseat. Testing demonstrated that the delethalized stick worked as intended when struck by the dummy. It also showed that the loads transmitted to the dummy were far less than with conventional sticks.

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1.0 INTRODUCTION

In November 1983, the final report for the initial crashworthy cyclic control stick effort was published (Reference 1). The report detailed the development and testing of a purely mechanical self-contained crashworthy cyclic control stick equipped with load-limiting and separating joint. The joint was to limit impact loads transmitted to a crewmember.

This report covers the additional development and testing of this concept by Simula Inc. to further delethalize the separating crashworthy cyclic control stick.

Using an impact load-limiting grip pad and reduction of the moving mass to reduce the inertial forces, two configurations were subjected to static and dynamic pendulum testing as in Reference 1. Additional destructive static testing was performed on both configurations, and one design was selected and tested in a full-scale dynamic test using an anthropomorphic dummy and a vertically stroking UH-60A Black Hawk crewseat.

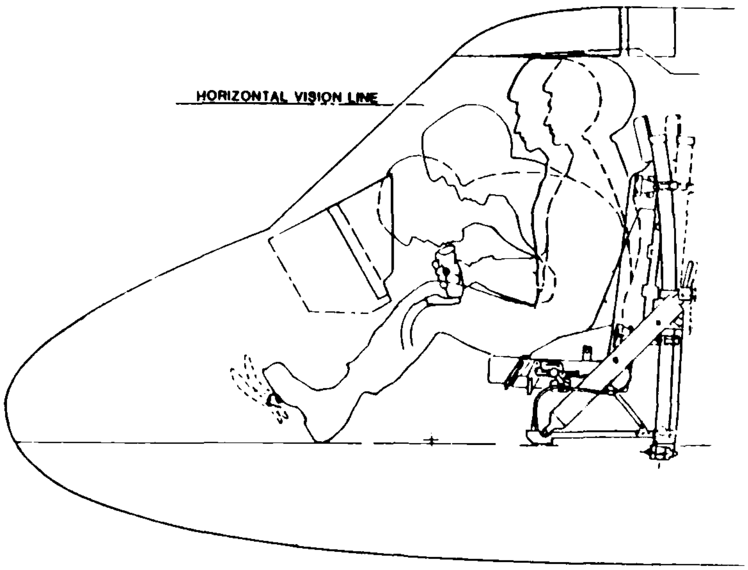
Testing demonstrated that the delethalized stick worked as intended when struck by the dummy. It also showed that the loads transmitted to the dummy were far less than with conventional sticks.

2.0 CYCLIC CONTROL STICK HAZARD

The cyclic control stick, located on the floor between the pilot's legs, is presently constructed of rigid tubing to meet the operational loads applied to it in flight. The location and rigidity of the cyclic stick present a potentially lethal impact hazard to the crewmember as can be seen in Figure 1, where the images of anthropomorphic dummies in high-speed films of vertical acceleration tests are overlayed on a UH-60A Black Hawk aircraft outline. Crewmember impact on the cyclic grip could occur about the head, neck, or upper torso. To locate a likely point of impact and velocity at impact, Program SOM-LA (Seat/Occupant Model: Light Aircraft) (References 2 and 3) was used to analyze typical crash orientations.

Figure 2 shows plots of a SOM-LA computer simulation for the 50th- and 95th-percentile crewmembers. The analysis also showed head impact velocities from 20 to 30 ft/sec directed from between vertical and 30 degrees aft of vertical. Unimpeded excursion of the 95th-percentile occupant's head c.g. reached approximately 15 in. above the floor during 95th-percentile potentially survivable crash pulses. This figure is important with regard to the remaining stationary stub height after separation.

STRIKE ENVELOPE: UH-60A CREWSEAT, 95TH-PERCENTILE OCCUPANT, 50-FT/SEC, 30-G FORWARD ($-G_X$) IMPACT (CYCLIC CONTROL IN NEUTRAL POSITION)



STRIKE ENVELOPE: UH-60A CREWSEAT, 95TH-PERCENTILE DUMMY, 42-FT/SEC, 42-G VERTICAL DROP WITH 13 DEGREES FORWARD PITCH (CYCLIC CONTROL IN NEUTRAL POSITION)

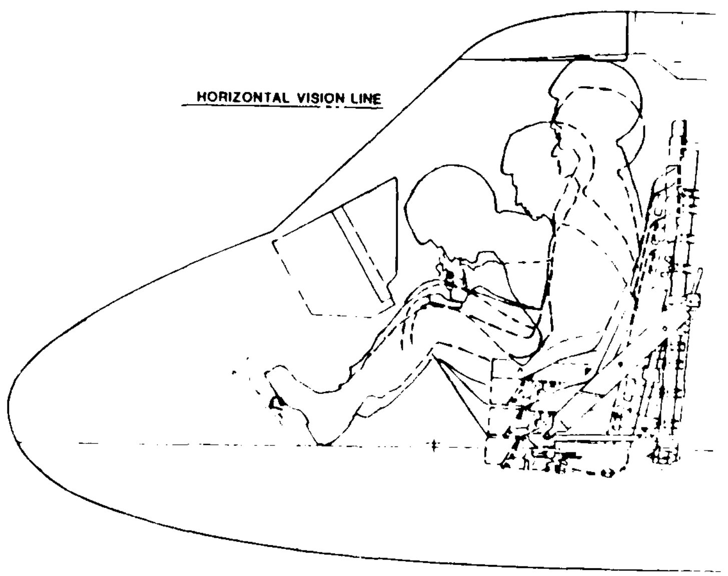


Figure 1. Possible cyclic control stick impact by crewmember in a UH-60A Black Hawk helicopter.

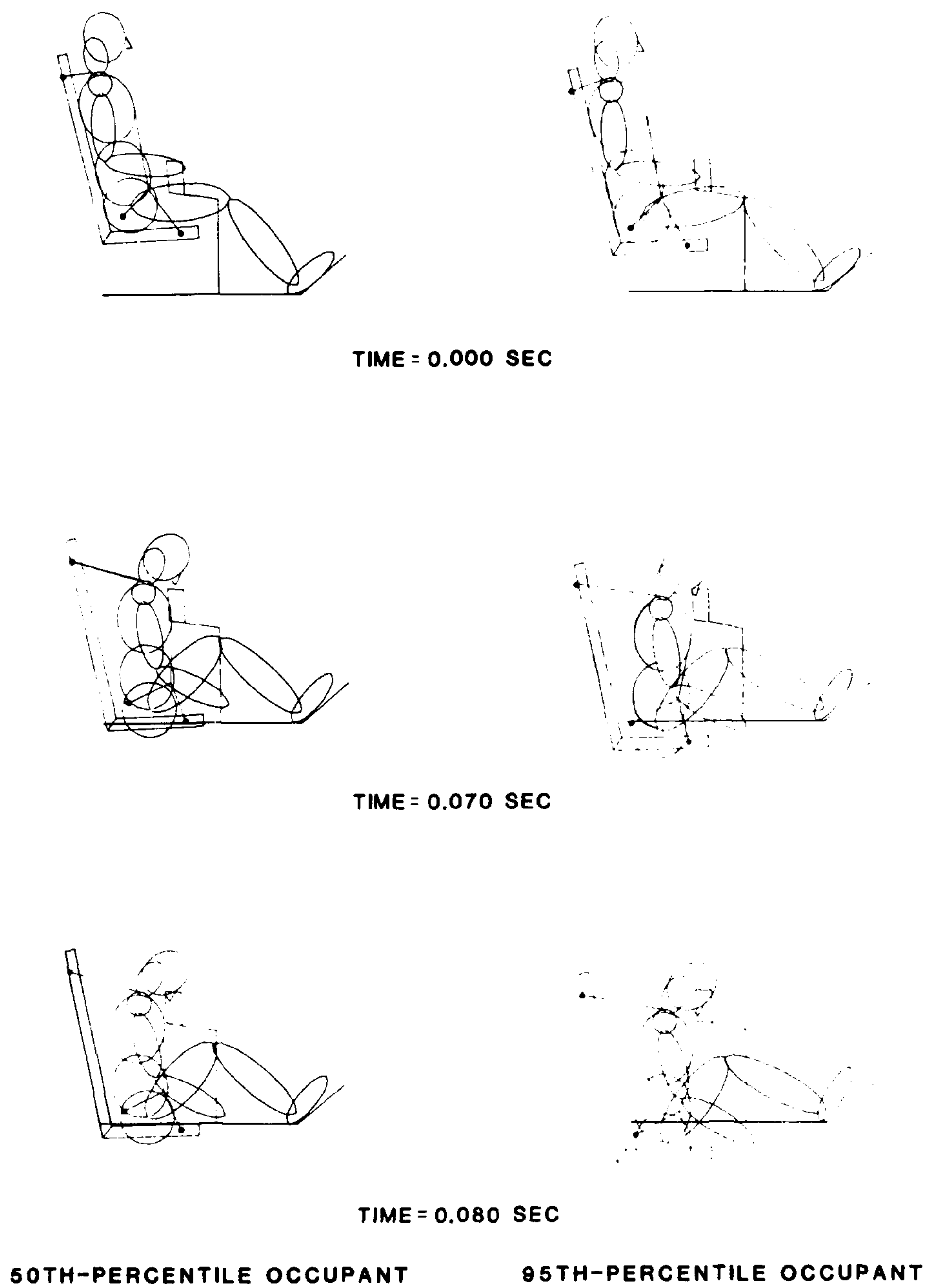


Figure 2. SOM-LA computer simulation.

3.0 DESIGN REQUIREMENT

Further development of the separating-joint crashworthy cyclic control stick was based on the design in Reference 1. The design is described in Section 4.0. This continued effort was narrowed to specific retrofit into the UH-60A Black Hawk aircraft. Based on recommendations of the above cited report, the design improvement was directed toward weight reduction of the moving portion of the stick and installation of an energy absorber (load-limiter) at or near the grip, both of which would reduce the occupant impact loads.

Two designs were developed for comparative testing. Design requirements retained from the earlier development program were as follows:

1. Provide 4 in. of vertical grip adjustment (±2 in. from nominal).

2. Accept the baseline grip (UH-60A) and also the newer grip (U.S. Army Aviation Systems Command Drawing No. 76-7477).

3. Accommodate at least 36 electrical conductors for grip switches.

4. Support emergency flight control loads required by MIL-S-8698 (Reference 4).

The program was divided into four tasks:

- Task I - Design

  Develop two designs, taking alternate approaches to material selection and/or impact load limiting and seeking to minimize mass while at the same time optimizing impact load limiting.

- Task II - Fabrication and Bench Test

  Fabricate two prototypes of each design and test statically to the emergency operational loads per MIL-S-8698 (Reference 4). Test the prototypes dynamically with a pendulum in the same manner as in Reference 1 and, subsequently, statically test to destruction one sample of each design in the longitudinal direction and one sample of each design in the lateral direction. From the test results, select the better design to continue on to Tasks III and IV.

- Task III - Analysis and Full-Scale Dynamic Tests

  By computer simulation (Program SOM-LA), select test parameters which are most likely to result in a cyclic stick/occupant impact. Based on these simulations, perform three full-scale dynamic tests using a UH-60A Black Hawk crewseat and an anthropomorphic dummy with a six-axis load cell installed in the neck.

- Task IV - Installation Procedure

  Prepare a step-by-step procedure for in-field installation of the crashworthy cyclic control stick into the UH-60A Black Hawk. (Refer to Appendix A for detailed procedure for the installation.)

4.0 PREVIOUS DESIGN

The earlier crashworthy cyclic control stick of Reference 1 is shown in Figures 3 and 4. Figure 3 also shows the outline of an existing UH-60A rigid-tubing cyclic stick. Figure 4 illustrates the separation mechanism of the design. A dovetail needle bearing joint separates as the energy absorber is crushed between the collar and the fork. As the stroke bottoms and the joint is released, the deflector contacts the fork and displaces the stick forward, off the fork.

The energy-absorber resistive load of 120 to 160 lb was chosen so that it would offer as little resistance as possible, and yet avoid inadvertant separation during emergency operational loads required by Reference 4.

References 5 through 8 were consulted to obtain allowable impact loads on the facial structure and neck not resulting in clinically significant fractures. No consequences of the various fractures were investigated. Figure 5 depicts the mean limits of impact loading on the various facial bones and neck cartilages.

Test results are shown in Figure 6. The crashworthy cyclic stick design did reduce the peak loads 50 to 80 percent and the duration by 44 to 50 percent, but loads were still in excess of the facial tolerances in some areas. The inertial test, where the moving portion of the stick was struck while suspended by fine wires in space, demonstrates that most of the remaining impact load was due to accelerating the mass of the stick, not the energy absorber or joint, which worked as designed. Comparative results are shown in Figure 7, where load reduction is illustrated.

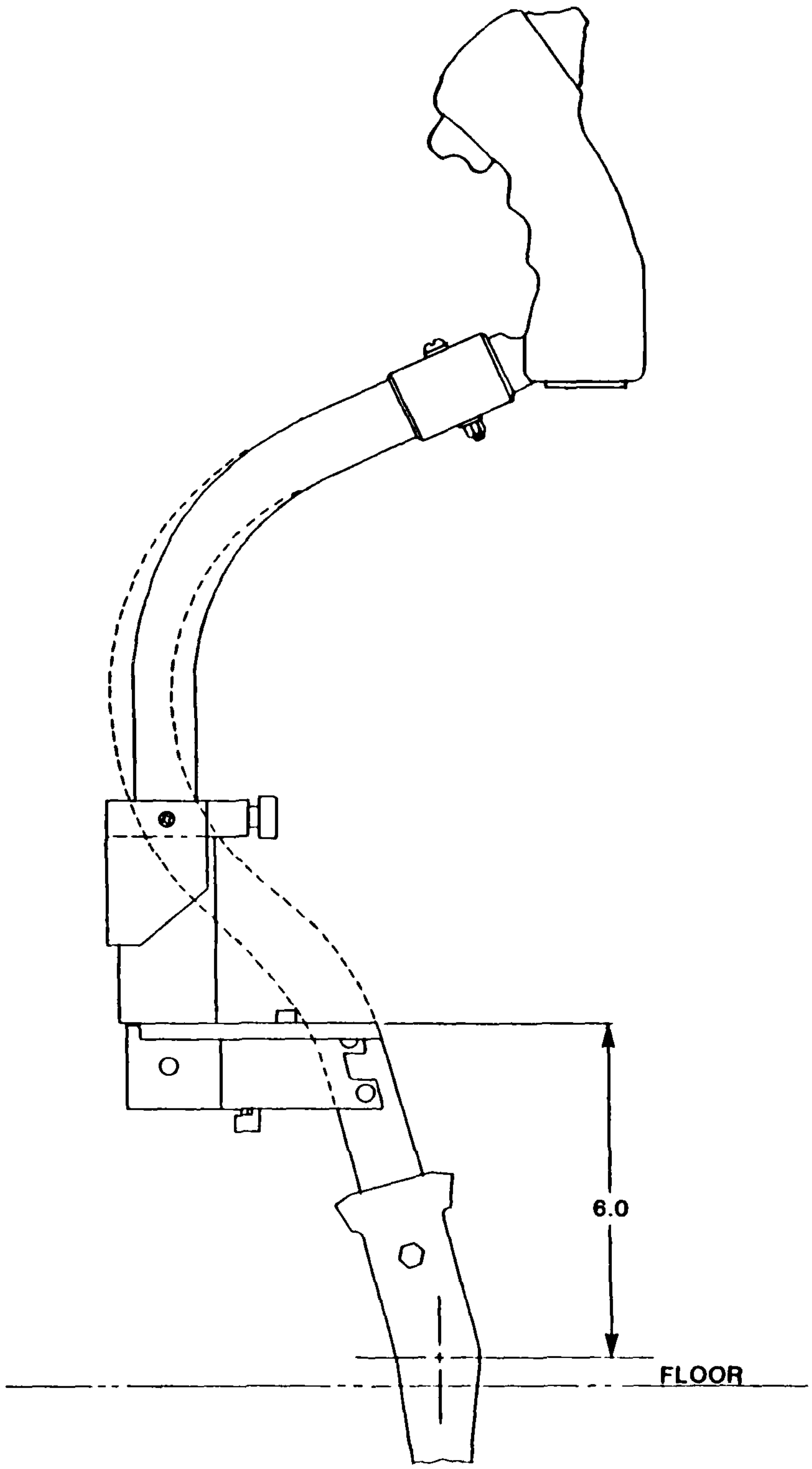


Figure 3. Crashworthy cyclic control stick - UH-60A Black Hawk helicopter.

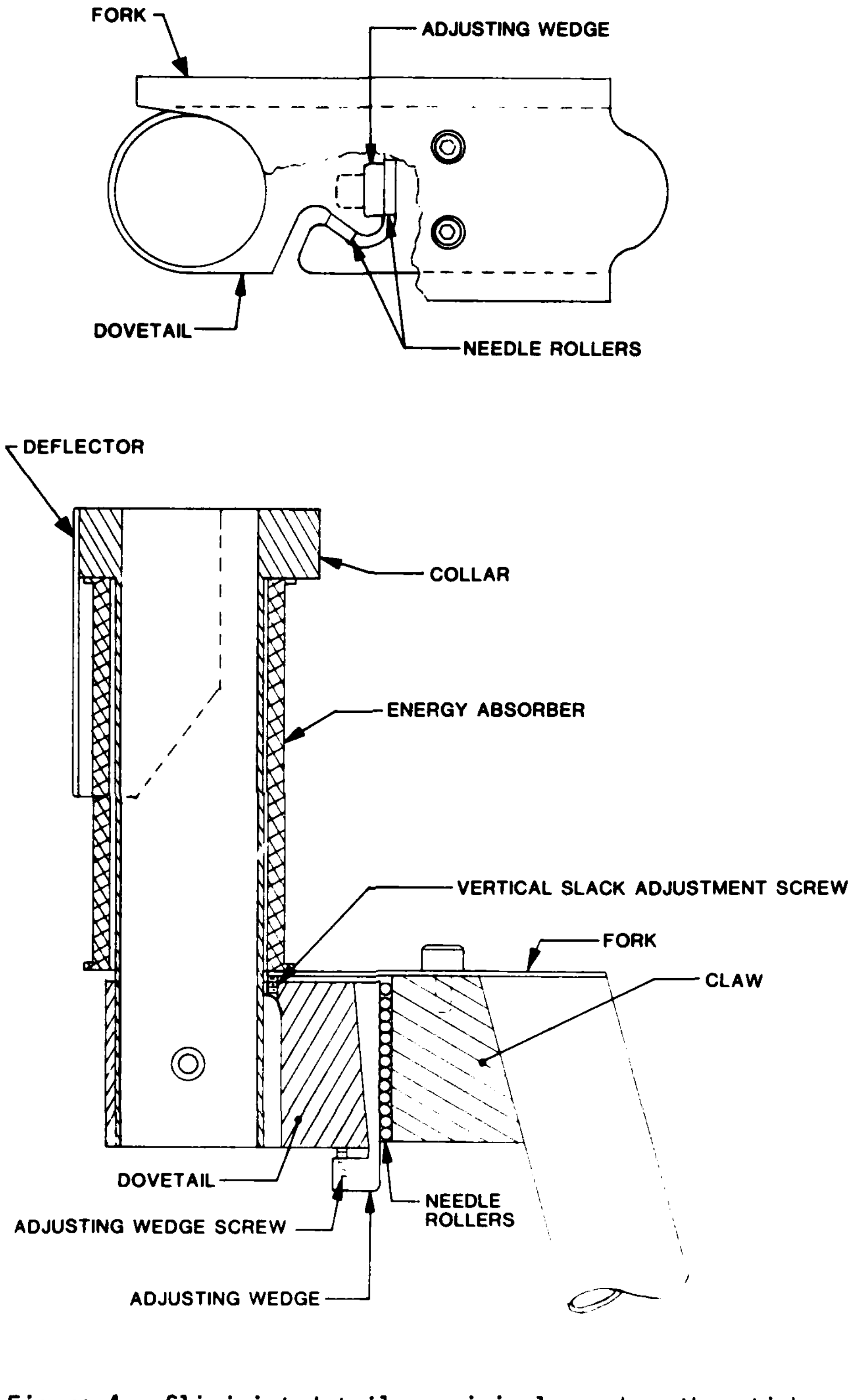


Figure 4. Slipjoint detail - original crashworthy stick.

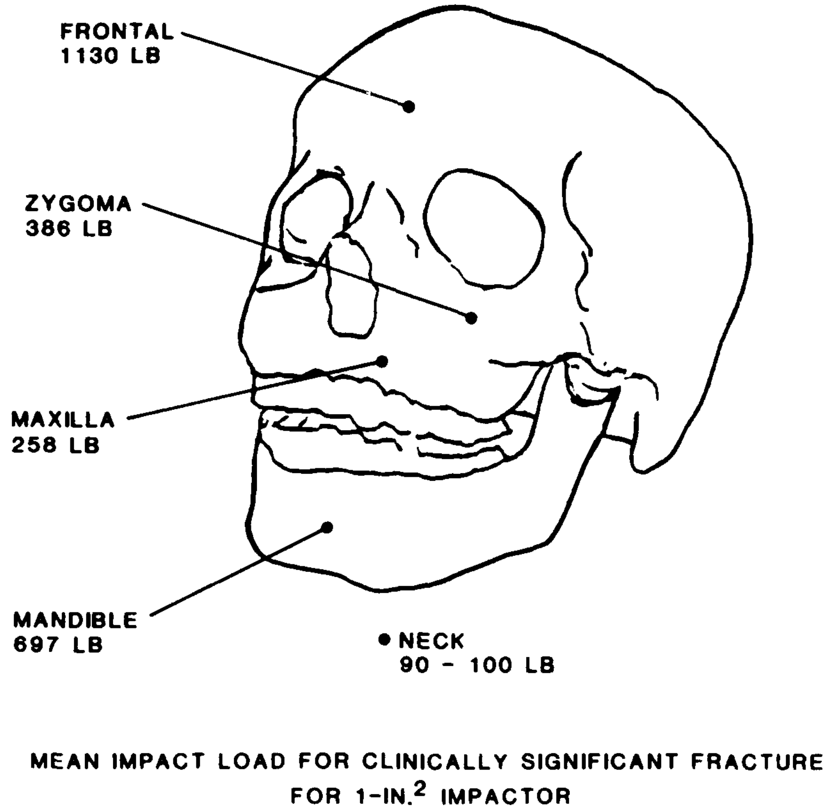


Figure 5. Facial bone impact tolerance.

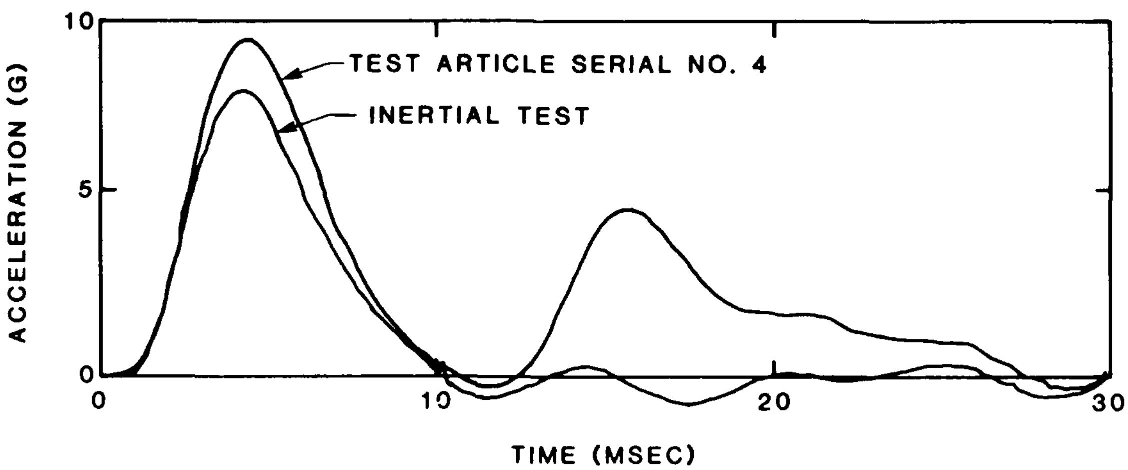


Figure 6. Test article and inertial test, acceleration-versus-time plot, previous testing.

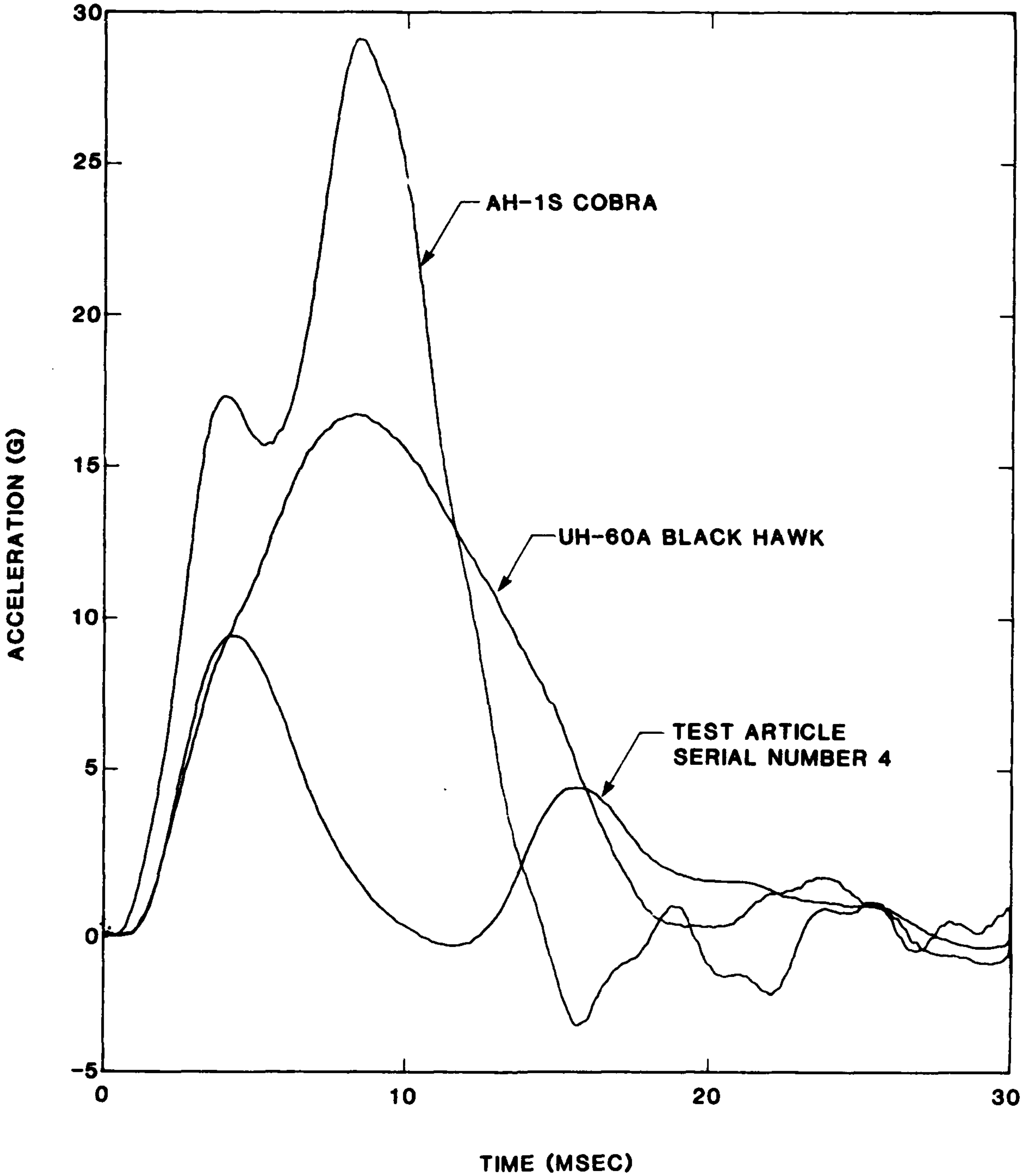


Figure 7. Existing UH-60A Black Hawk and AH-1S Cobra and crashworthy cyclic control stick plot.

5.0 NEW DEVELOPMENT

In this program, Simula Inc. sought to define and reduce cyclic stick impact forces on a crewman during a crash. Many new concepts and some revived concepts from the previous effort (Reference 1) were considered. The concepts were presented to Sikorsky Aircraft and the Army for careful scrutiny. Many concepts were eliminated from the standpoint of not having a passive system. A system which relies on pyrotechnics or an alternate event to reduce injury was deemed difficult to qualify and too costly. Also, some concepts were rejected because it was cost effective to continue to use the existing grip rather than to design a new grip. Of those concepts eliminated by Sikorsky and the Army, a few showed great promise for reducing or eliminating crewman injuries. A brief discussion follows on each of these concepts.

Figure 8 shows a concept which utilizes much of the original separating stick design (Reference 1) but goes one step further by adding an alternate event trigger. The trigger may be activated by a crash sensor on the aircraft or displacement of the seat. This concept virtually removes any possibility of occupant impact with the cyclic control stick.

Redesigning the grip itself was an attractive idea. Figures 9, 10, and 11 show methods to limit loads at impact. An increase in area on the top of the grip would reduce pressures on facial bones. The grip could be designed to crush or rotate to limit loads. An airbag device, as shown in Figure 10, could give a "soft" impact and deflate to limit loads.

Other concepts that deal with the stick structure were considered. A flexible upper tube and a break-free adjustment of the upper tube, as shown in Figures 12 and 13, would allow movement and limit loads. The break-free upper tube would shear the adjustment pin and retract at a chosen load.

The concepts which were not elimimated included a slip joint and adjustment mechanism similar to the original crashworthy stick. Also, mockups of two concepts for a load-limiting device on top of the grip were fabricated for further evaluation.

In the chosen concepts, mass reduction was of primary importance. The ideas for reducing the moving stick mass consisted of changing the material of the separating joint from tool steel to aluminum, with hardened steel inserts to support the bearing loads. The energy absorber was redesigned to eliminate many of the components in the original stick design. Also, the majority of the energy absorber weight was transferred to the nonmoving stub, where it will not transmit inertial loads to the occupant.

5.1 GRIP PAD

Many of the load-limiting concepts developed for the grip and evaluated by the Army were eliminated for reasons requiring a redesign of the grip itself. But two concepts which did pass this evaluation were fabricated as mockups. One load-limiting device was made of a 3-in.-high crushable ring of composite material, the other was made of a 2-in.-high crushable pad of foam. Each sample was mounted on top of the grip and evaluated by Sikorsky Human Factors engineers (see Figure 14). Sikorsky Human Factors evaluated

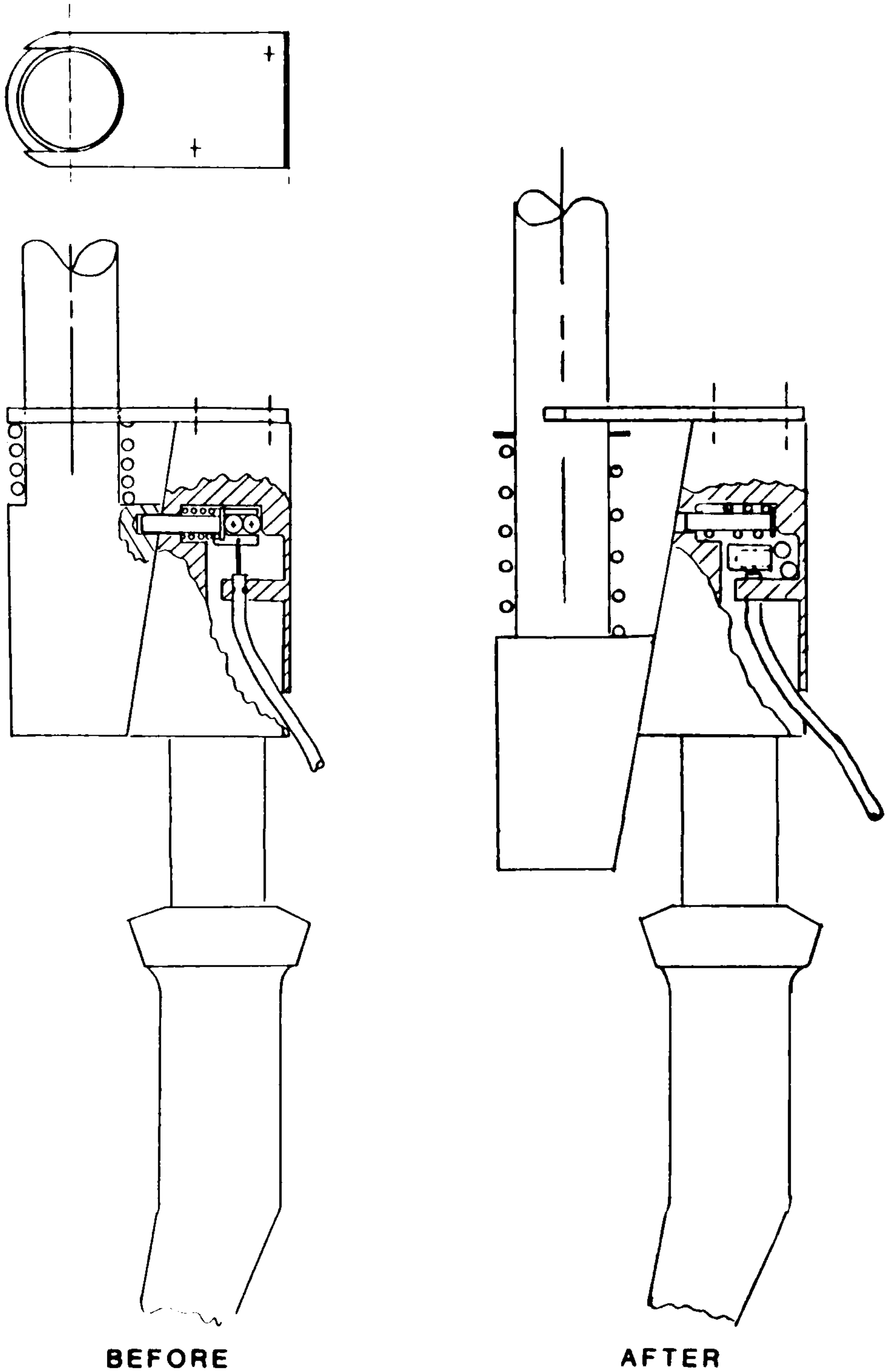


Figure 8. Stick separation triggered by event other than occupant impact.

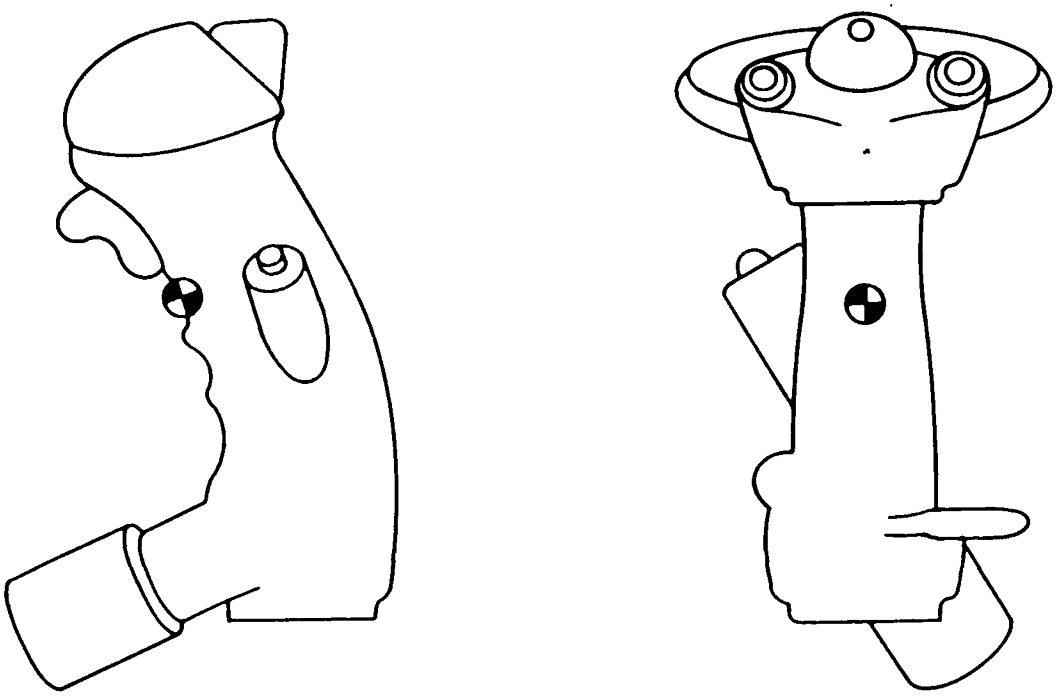


Figure 9. UH-60A grip with increased contact area.

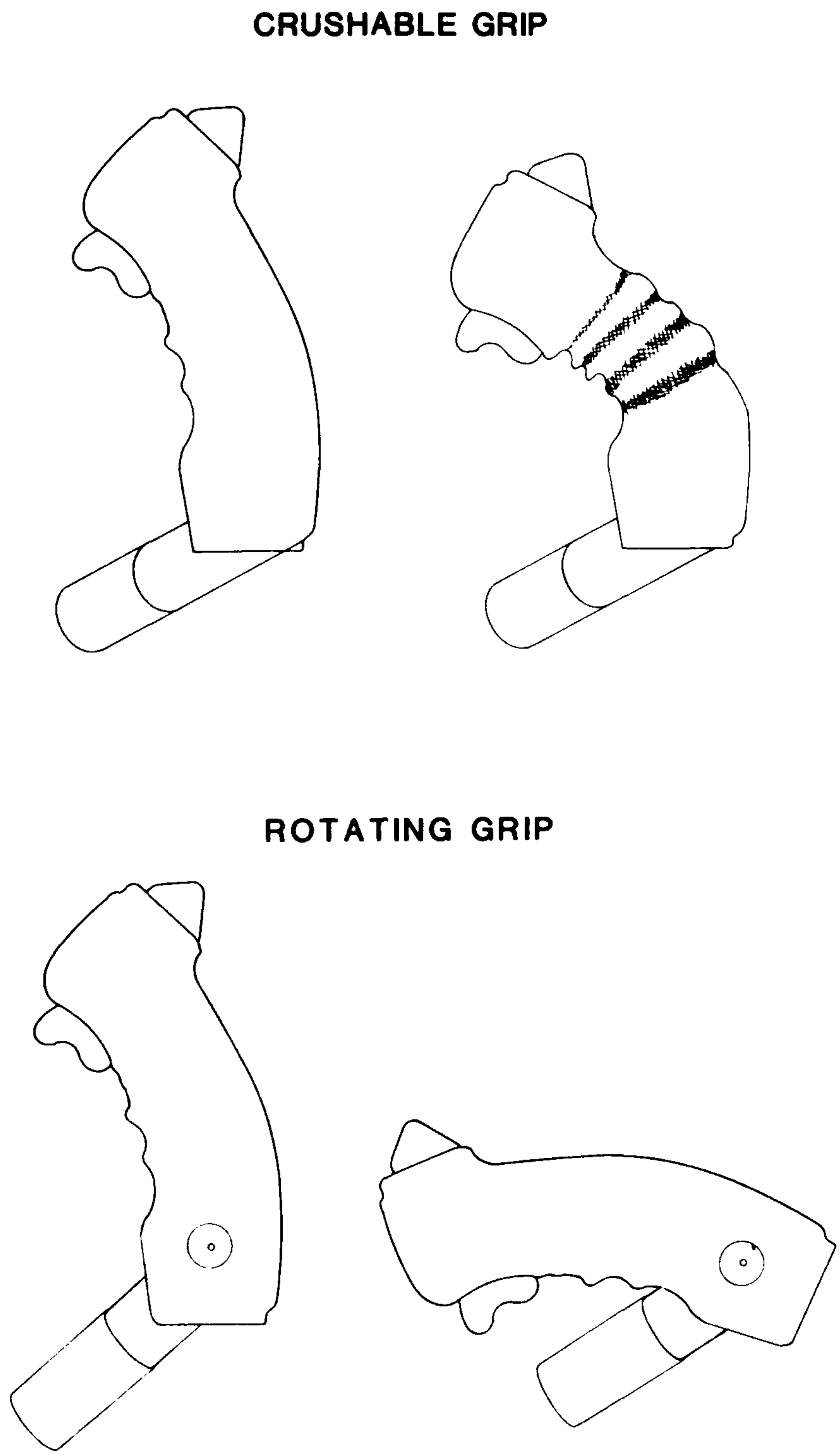


Figure 10. Crushable and rotating grips.

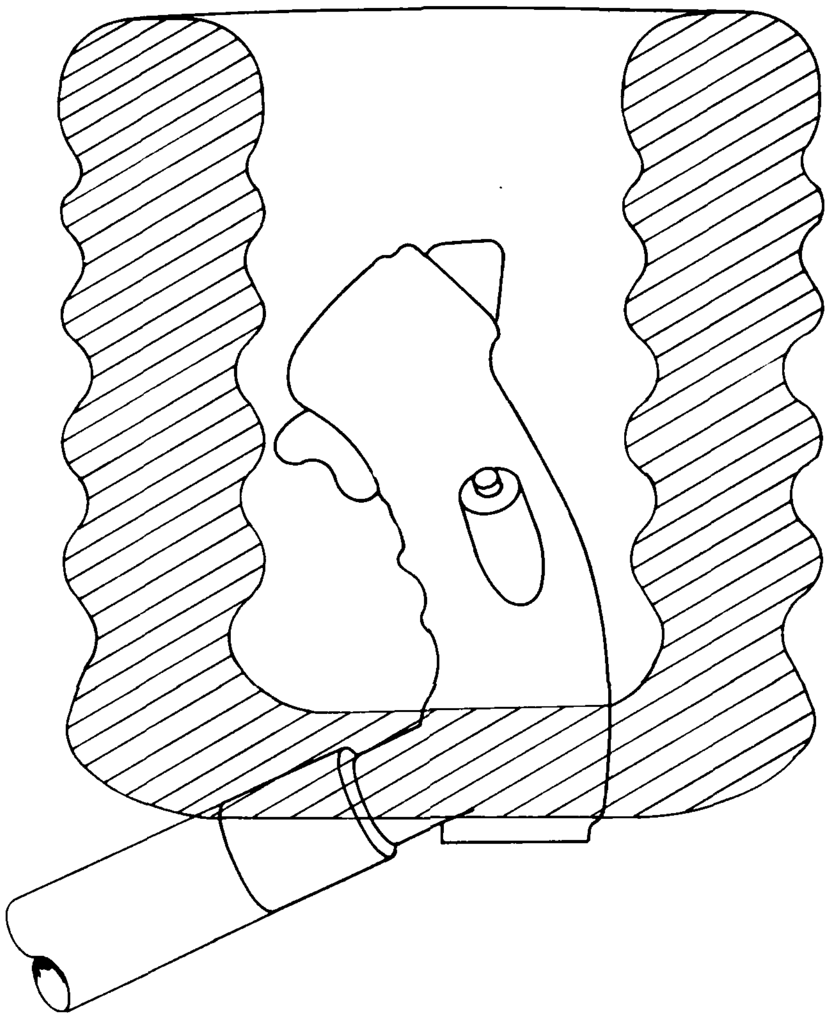


Figure 11. Annular airbag about grip deployed position.

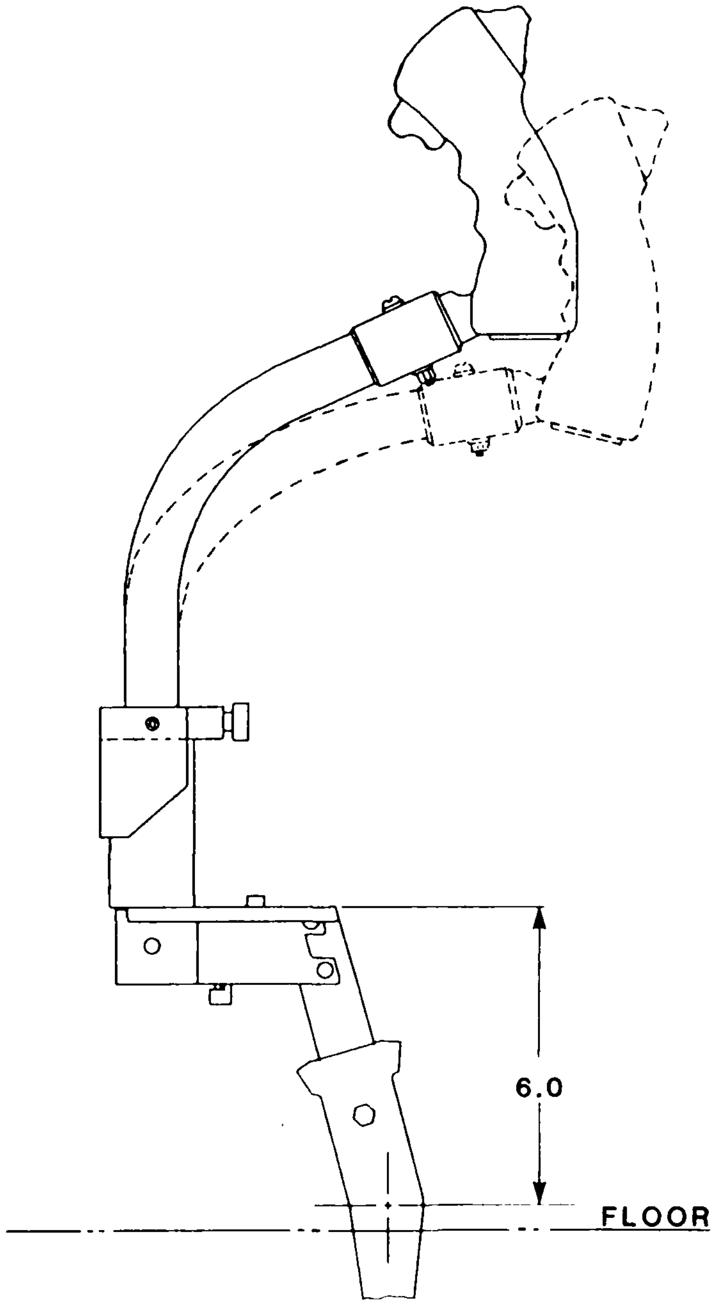


Figure 12. Flexible stick assembly.

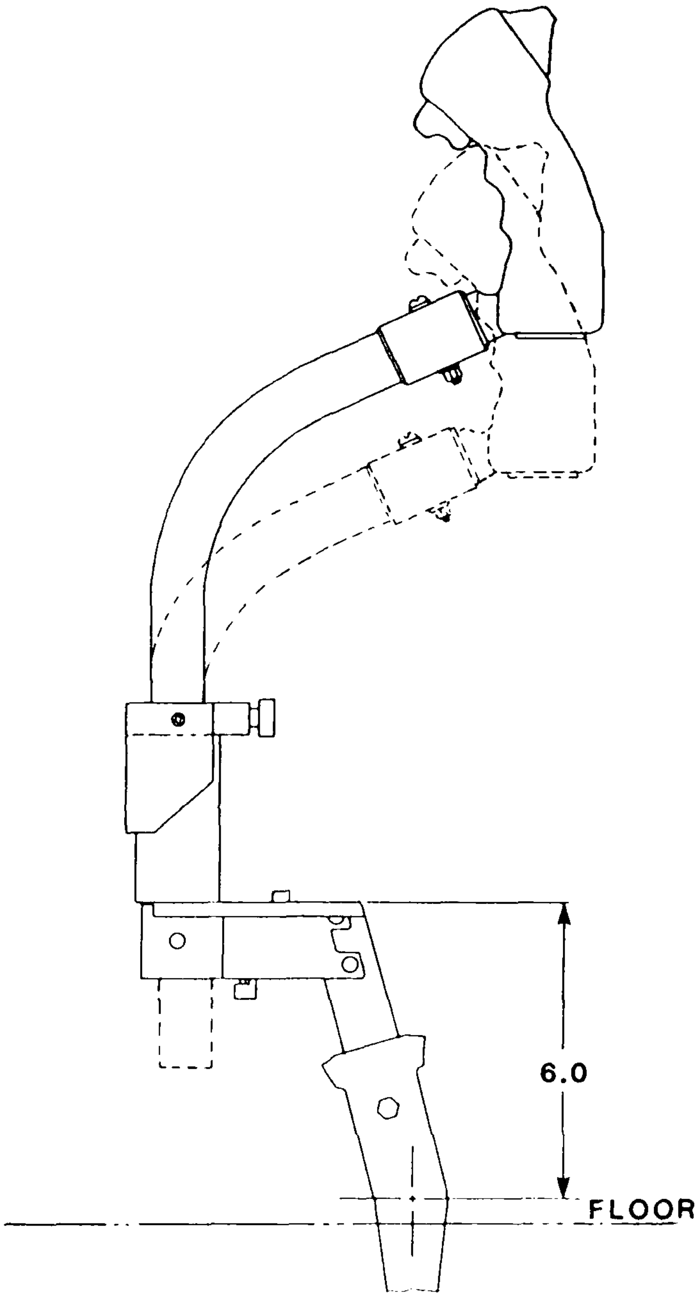


Figure 13. Break-free adjustment assembly.

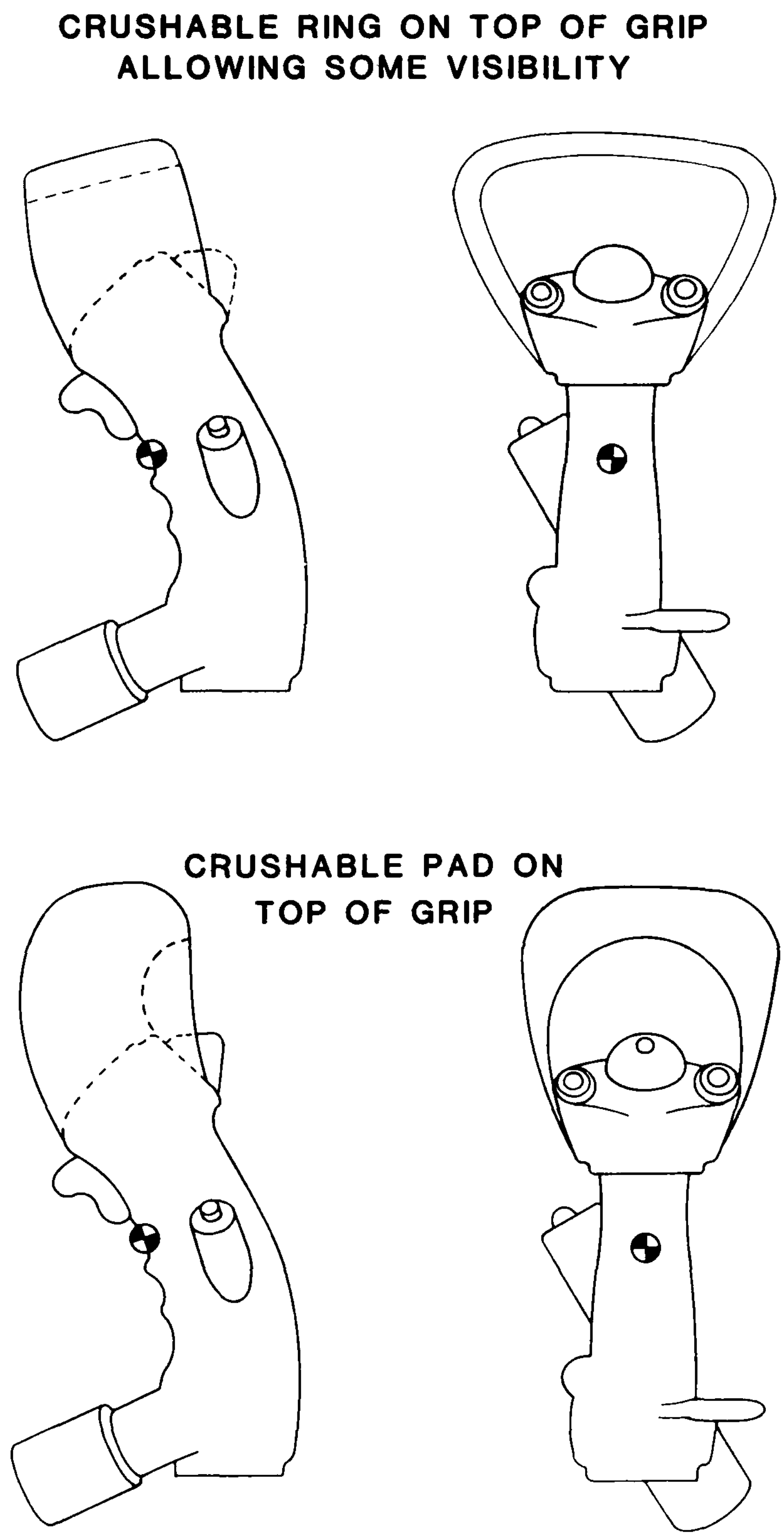


Figure 14. Crushable ring and pad on top of the grip.

the samples for obscurity of the instrument panel and flammability. The ring design and the pad design, as shown in Figure 14, were both rejected for obscuring portions of the instrument panel, but Sikorsky recommended a modified foam pad design and set a maximum height for the pad at 1.5-in. Figures 15 and 16 show how the 2-in.-high configuration would block portions of the instrument panel from sight.

The next step in the development of the grip pad was to determine an allowable crush load and find the density of foam which would produce this crush load. A computer model was developed to optimize crush load of the foam pad with impact loads on an occupant. The computer model is discussed later in this section. A maximum crush load of 200 lb was determined suitable for the conditions expected at head/stick impact. Different densities of polyurethane foam pads with various covers were fabricated in the approved shape and statically tested. A urethane-covered 6.5-lb/ft^3 density foam gave the proper force-deflection characteristics necessary for minimum occupant impact load. Figure 17 shows the results of the foam pad crush tests.

The final design of the grip pad, shown in Figure 18, will limit impact loads by means of crushing; also, the increase in contact area on top of the grip will contribute to the delethalization of the cyclic stick.

The pad material consists of a polyurethane core wrapped with a nylon mesh just beneath the surface. The mesh protects the foam from wear and tear and holds the foam rigidly on the grip during a crash.

5.2 JOINT REDESIGN

The dovetail joint of the original crashworthy cyclic stick was redesigned with weight reduction and production costs in mind. The new configuration (see Figure 19) features an asymmetric design with two rows of 1/2-in.-long needle bearings facing on a row of 1-in.-long needle bearings. The use of hardened steel inserts for the bearing races eliminates the need for the complicated precision grinding of the first separating joint design. The joint was also heightened to 2 in., which, combined with the longer bearings, is responsible for lowering contact stresses in the bearings. The asymmetric configuration leaves the rear of the dovetail clear for attachment of an energy absorber (load limiter).

5.3 ADJUSTMENT MECHANISM

Careful consideration was given to the transfer of the adjustment mechanism with its associated mass to the nonmoving stub. However, design constraints for the adjustment mechanism to be located on the stub would lead to a 10- to 12-in. stub height (see Figure 20). This was unacceptable because SOM-LA data shows that the head c.g. of a 95th-percentile occupant could reach as low as 15 in. above the floor. Therefore, the adjustment mechanism was left on the moving portion of the stick. The concept chosen (see Figure 21) has the lowest stub height. To operate the adjustment mechanism, the cam lever is lifted, pulling the lock pin out of the grip tube. The grip and tube is free to travel a total of 4-in. The lever is lowered to lock the stick in place.

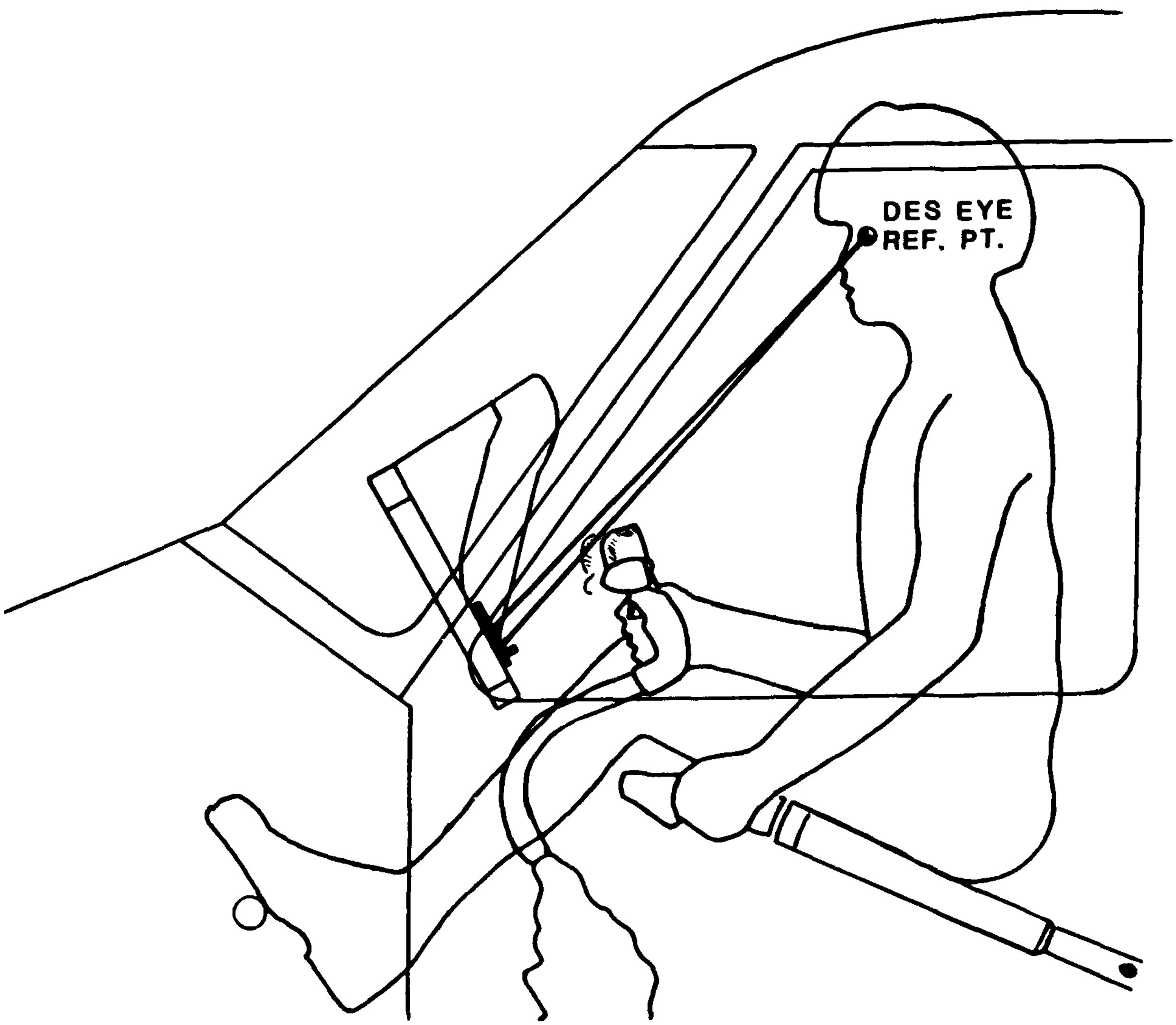


Figure 15. Line of sight over 2-in.-high grip pad.

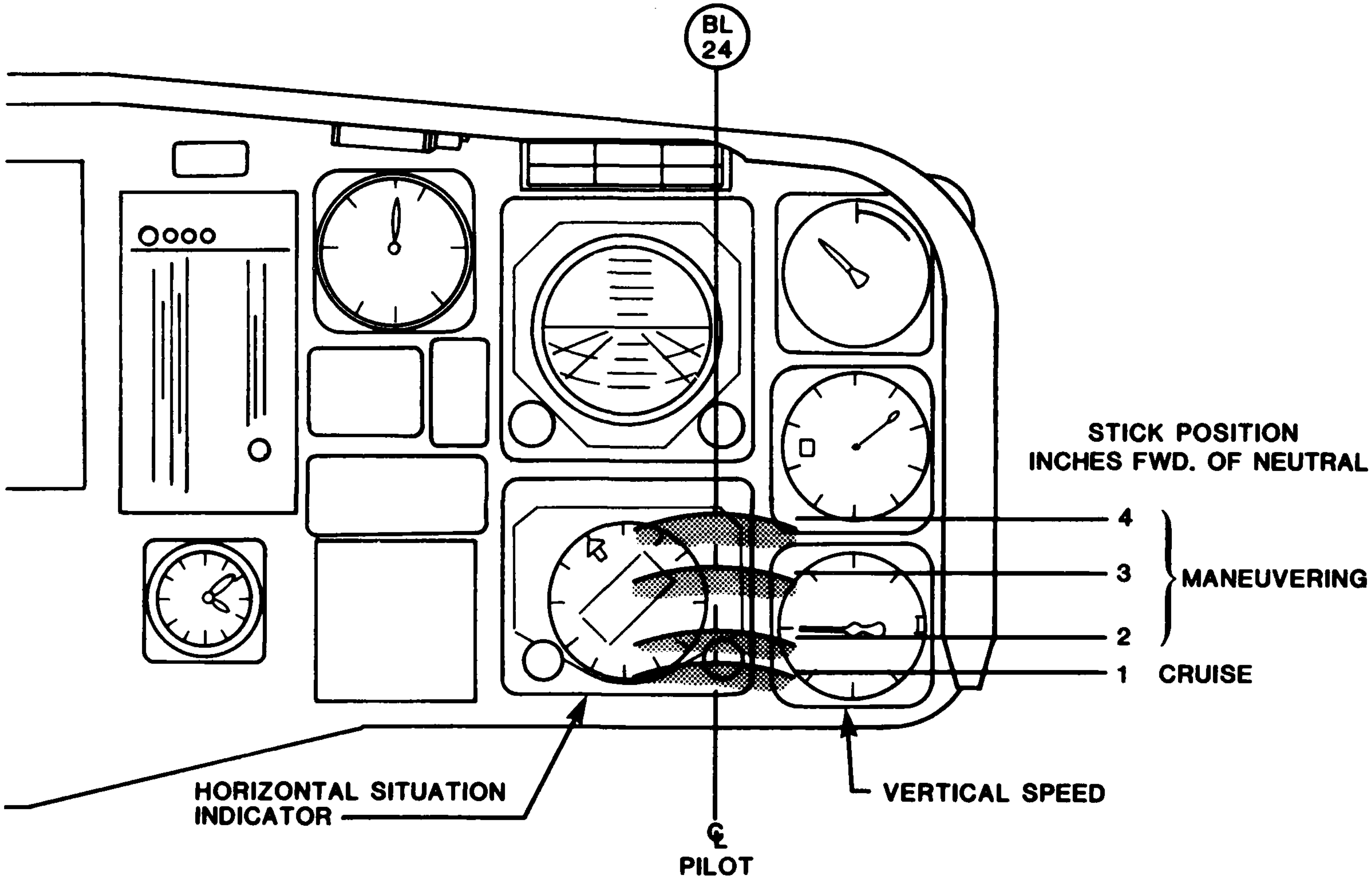


Figure 16. Panel obscured from design eye reference point by 2-in.-high foam block on grip.

SIZE AND SHAPE:

EVALUATED BY SIKORSKY HUMAN FACTORS ENGINEERING

MATERIAL:

PAD:

POLYURETHANE FOAM

- THIN SELF-SKINNING
- MOLDABLE
- VARIABLE DENSITY
- CLOSED CELL
- LIGHTWEIGHT

COVER:

URETHANE WITH NYLON MESH

- TOUGH
- DURABLE
- SEALS FOAM
- ONLY MINOR LOAD-DEFLECTION EFFECT

CRUSH TEST RESULTS: 6.5 pcf DENSITY FOAM

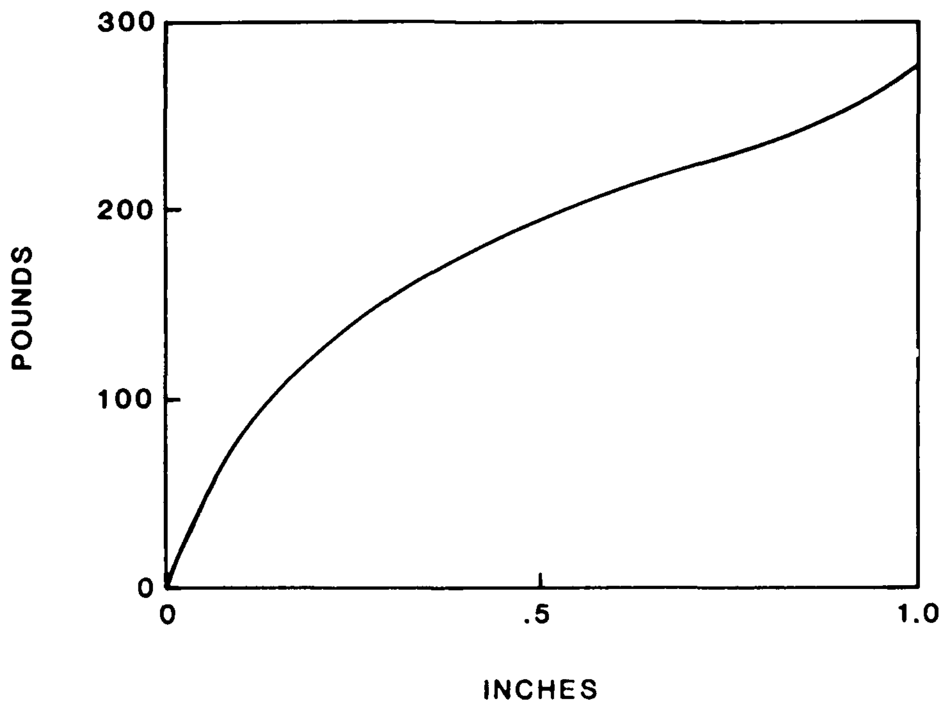


Figure 17. Grip pad development and crush test results.

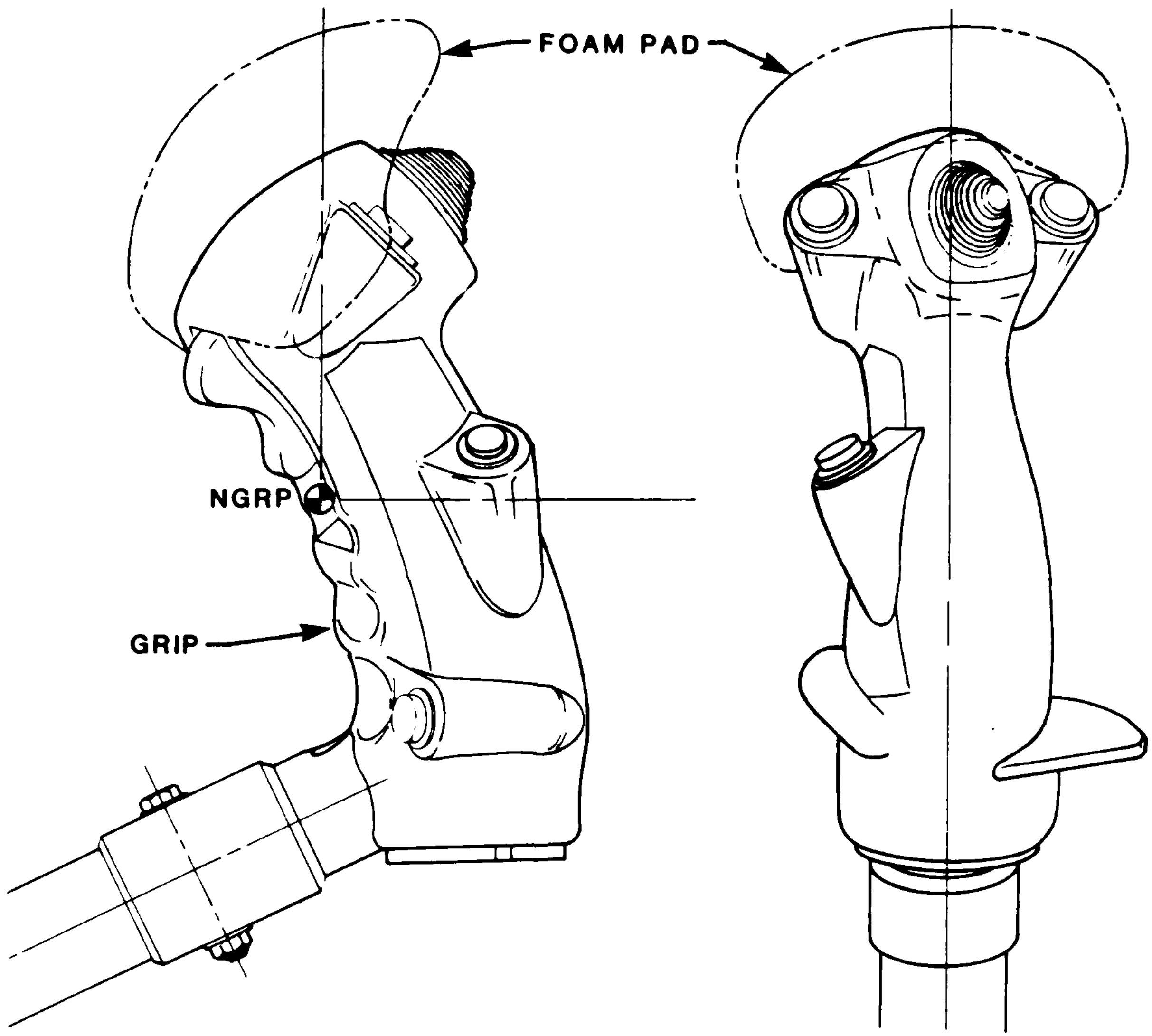


Figure 18. Load-limiting grip pad.

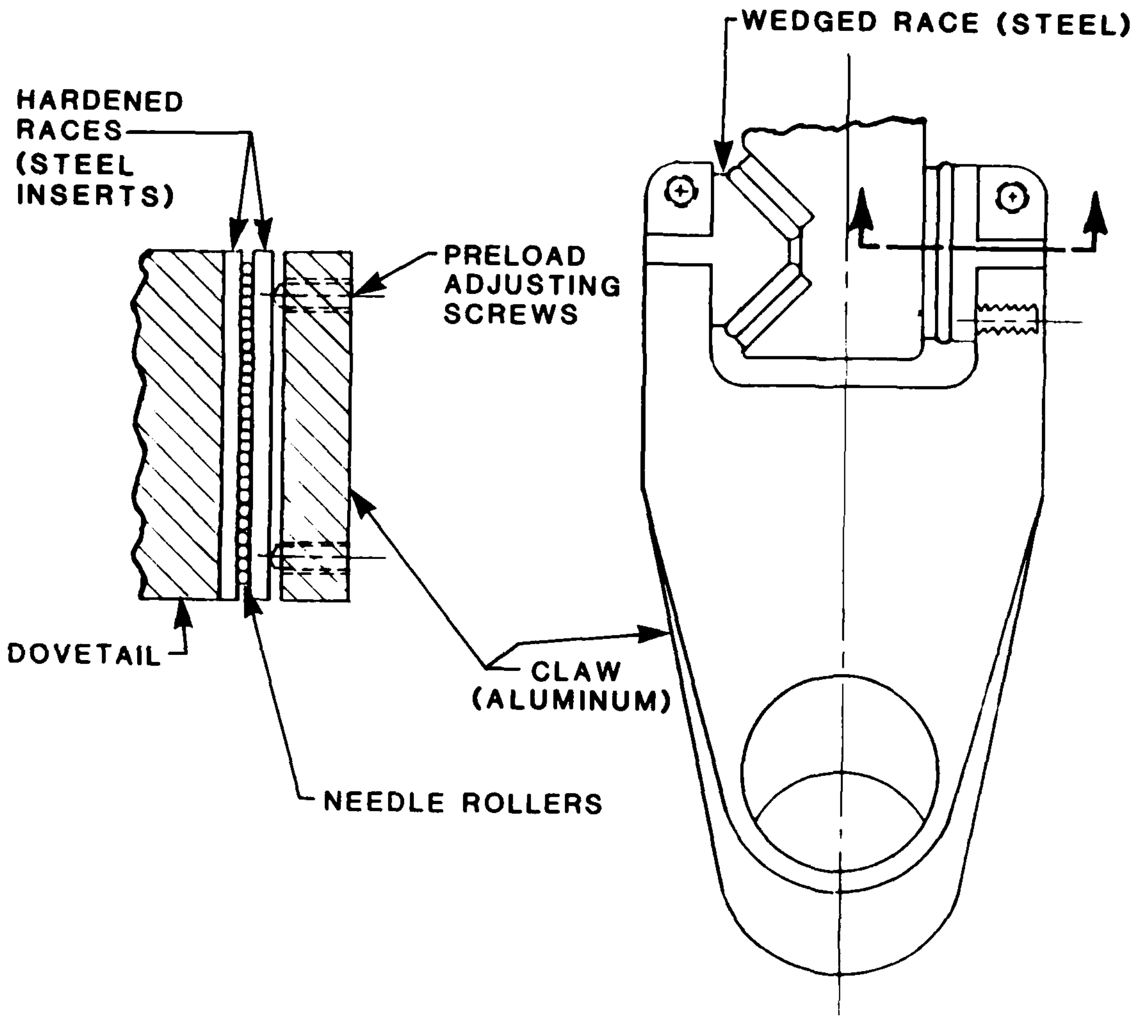


Figure 19. Separating needle bearing joint.

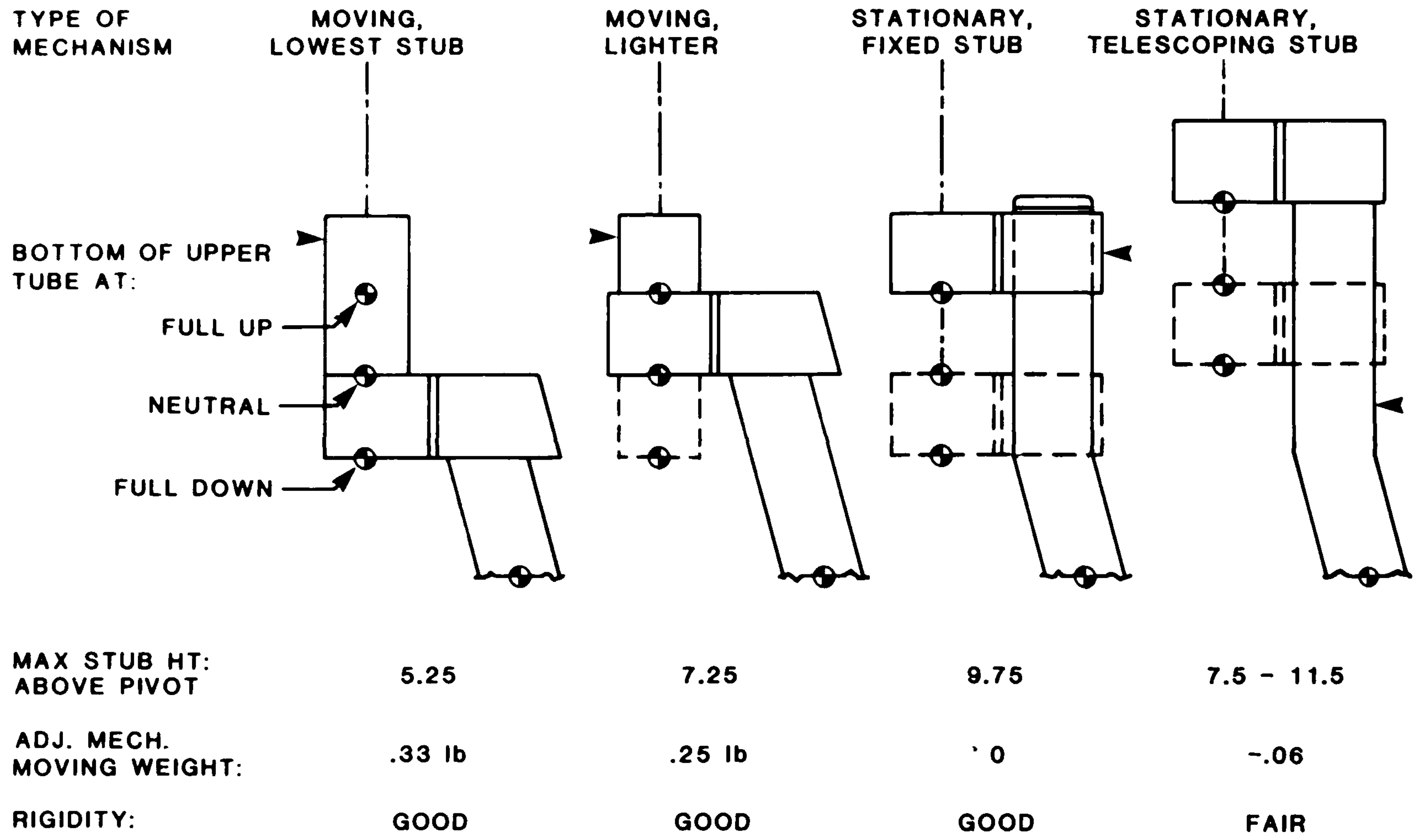


Figure 20. Adjustment mechanism trade-offs.

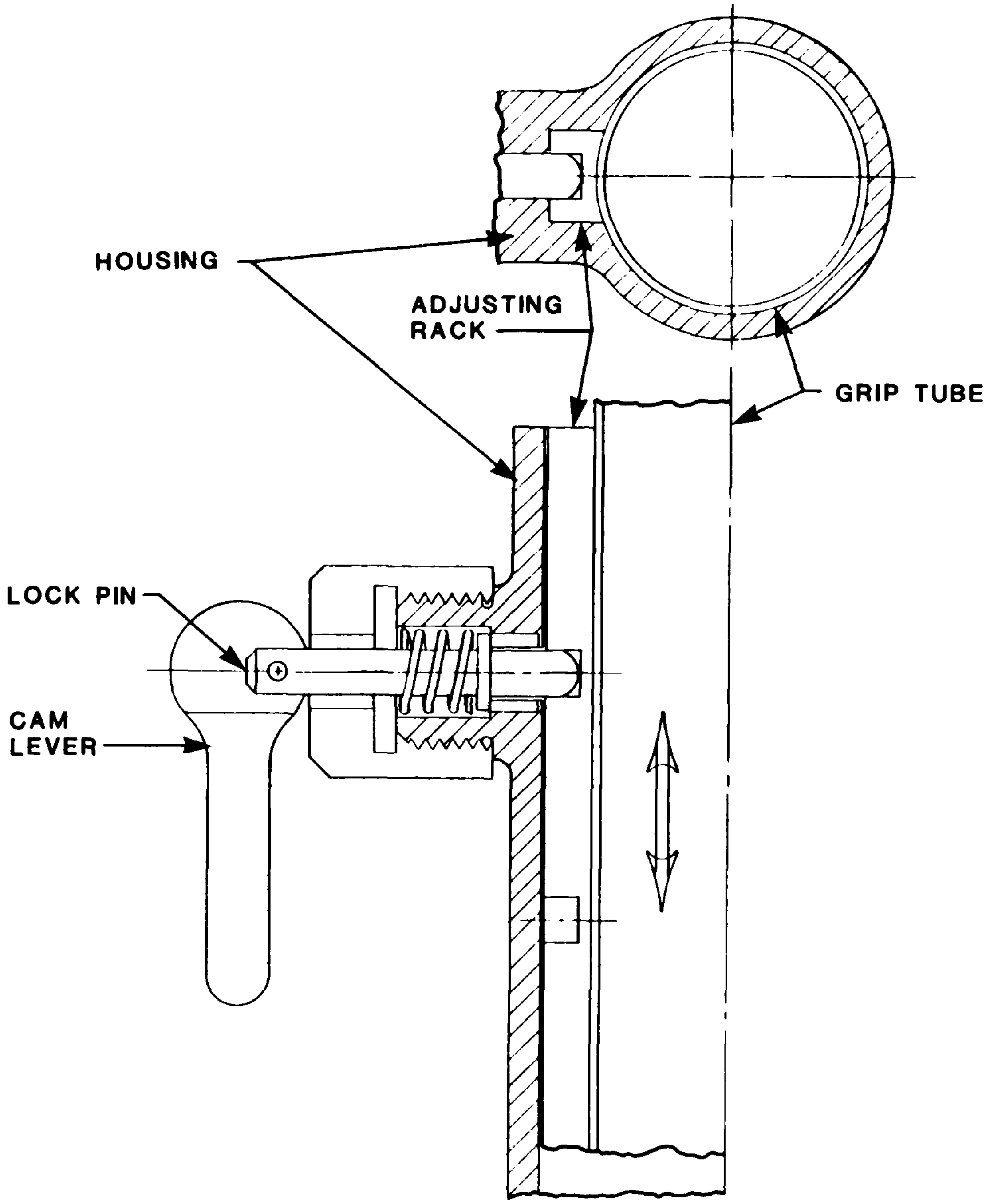


Figure 21. Height adjusting mechanism.

5.4 ENERGY ABSORBER REDESIGN

Because the energy-absorbing mechanism was transferred from the moving to the nonmoving portion of the stick to reduce the inertial mass, the honeycomb tube energy-absorber design on the original stick could not fit in the available space. High cost and the difficulty in protecting the honeycomb in the operational environment (corrosion and incidental impact) were other reasons why the honeycomb energy absorber was abandoned. Two alternate configurations were proposed, either of which could be placed in the same space within the separating joint.

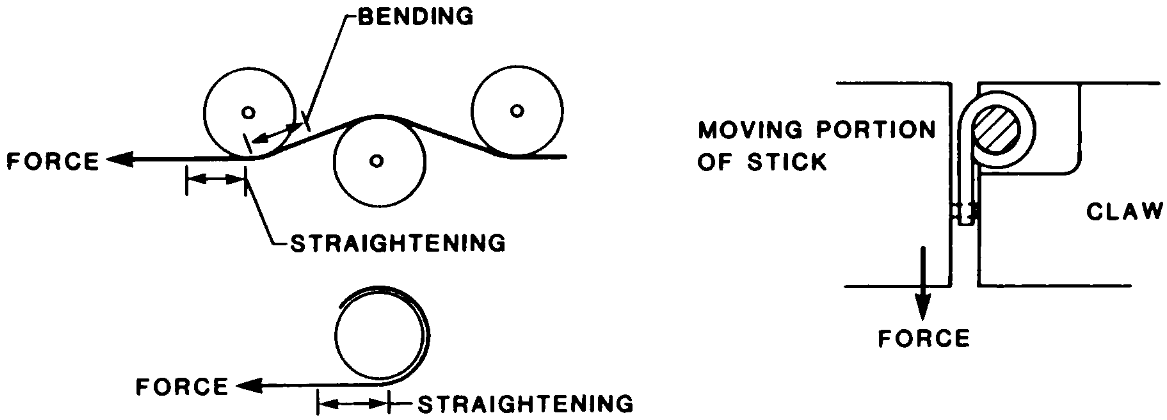
The first energy-absorbing (load-limiting) configuration provides a constant load throughout the separation process of the joint. The second configuration offers an intermittent resistive load where resistance is provided at the beginning and at the end of the stroke. Computer analysis showed that the latter will provide less resistance to the acceleration of the moving portion of the cyclic stick, thereby reducing the impact load, while still maintaining a "fail-safe" capability against inadvertent separation.

The constant force energy absorber, as shown in Figure 22, is a variation on the wire bender energy absorber, which bends and straightens a wire as it is pulled through a series of rollers. For the relatively low load required for this application, a single straightening operation for two wires is sufficient. Thus, the energy absorber consists of two wires wound around a steel bushing. The bushing is free to spin on a shaft while the wires are pulled off the bushing. The assembly provided a constant resistive load. This energy absorber configuration duplicates the function of the original honeycomb energy absorber, but in a much more compact, lightweight, economical, durable package.

For the intermittent energy absorber, a tab bender has been adapted to fit in the same space as the wire bender energy absorber. The tab bender, as shown in Figure 23, uses a small, thin, cantilevered beam overlapped by a thicker tab. The beam starts to deflect at its maximum resistance load and then the load drops off slightly. Between bendable tabs, the moving portion of the stick is free to stroke without resistance. The second tab will stop the separation of the joint if the stick is inadvertently struck while in flight. The force-versus-deflection curve can be shaped as desired by placement of the tabs.

5.5 SEPARATING CYCLIC STICK MODEL

A computer model was developed to predict and optimize the dynamic response of the separating stick as a system. In Figure 24, the moving stick mass is sandwiched between two resistive forces - the grip pad crush load and the load-limiter in the separating joint. Once impacted by a mass, the grip pad will crush while the load rises. When the pad force equals the joint resistive force, the moving portion of the stick begins to stroke. Properly optimized, the grip pad should complete maximum crush when the velocities of the impacting mass and the stick are equalized, and when the release of resistance in the stick joint occurs simultaneously. At this point, maximum loads imposed on the occupant are reached and minimized. Changes in the grip pad density will also play a role in the optimization process.



- STAINLESS STEEL FOR ENVIRONMENTAL PROTECTION
- COMMON SPRING WINDING FABRICATION
- LIGHTWEIGHT
- NO ADDITIONAL STRUCTURE REQUIRED
- SMALL SIZE

STATIC TEST RESULTS:

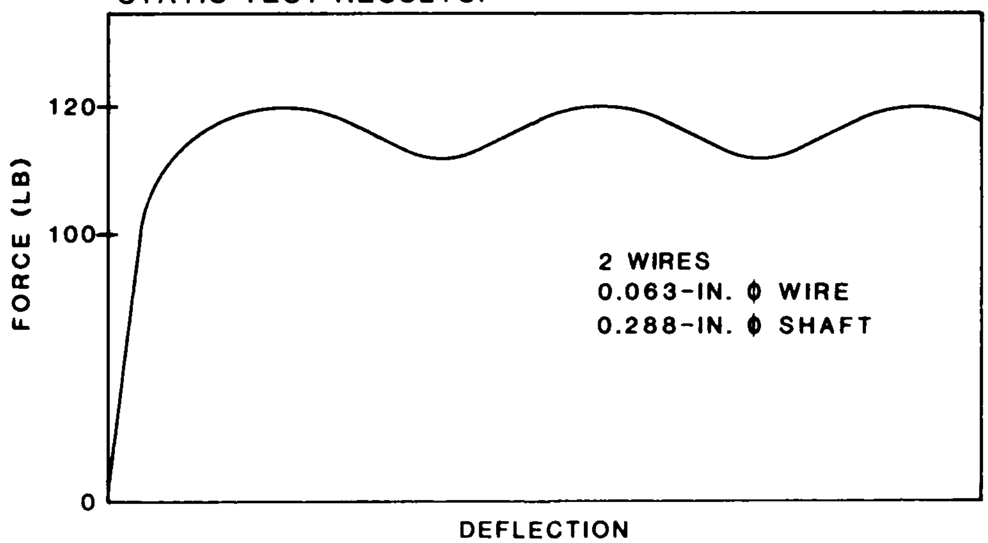
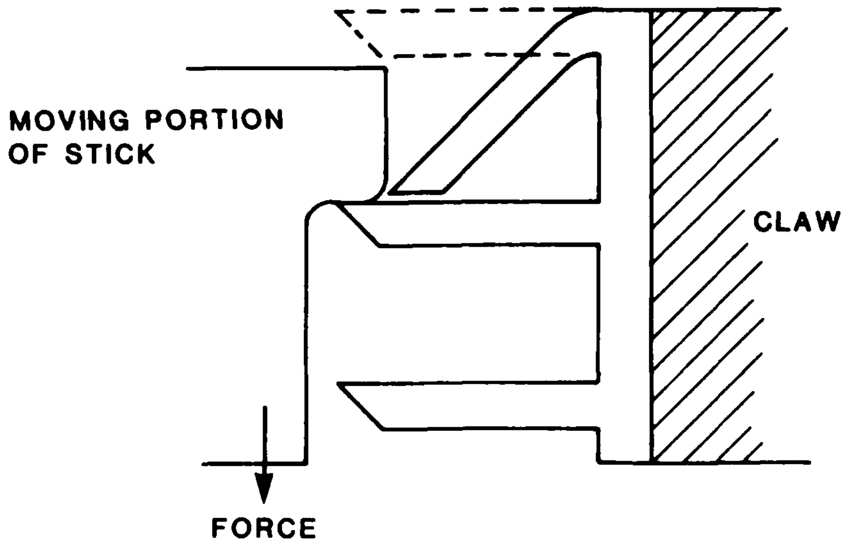


Figure 22. Wire load-limiter development and static test results.



- STAINLESS STEEL FOR ENVIRONMENTAL PROTECTION
- LIGHTWEIGHT
- NO ADDITIONAL STRUCTURE REQUIRED
- SMALL SIZE

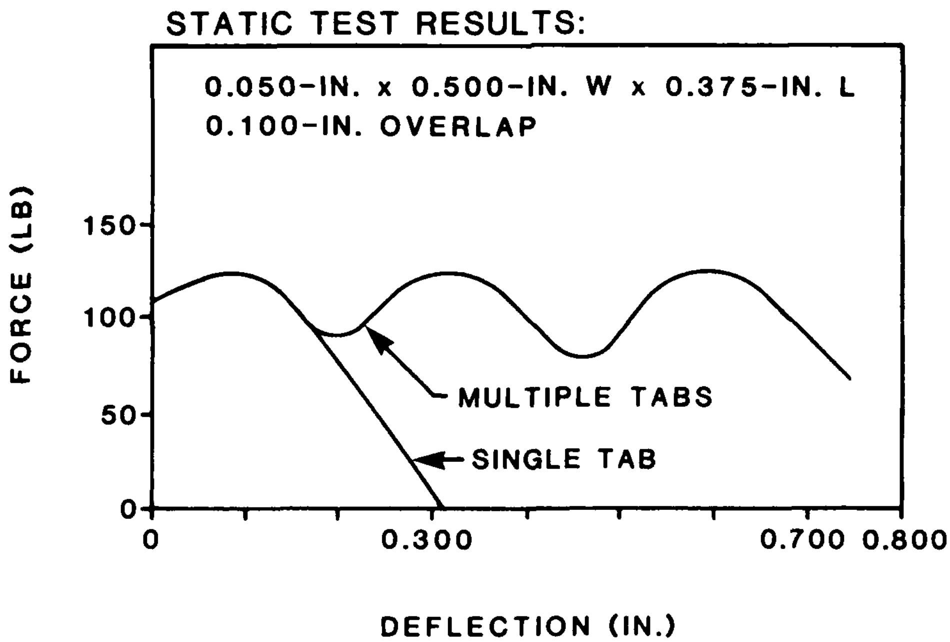
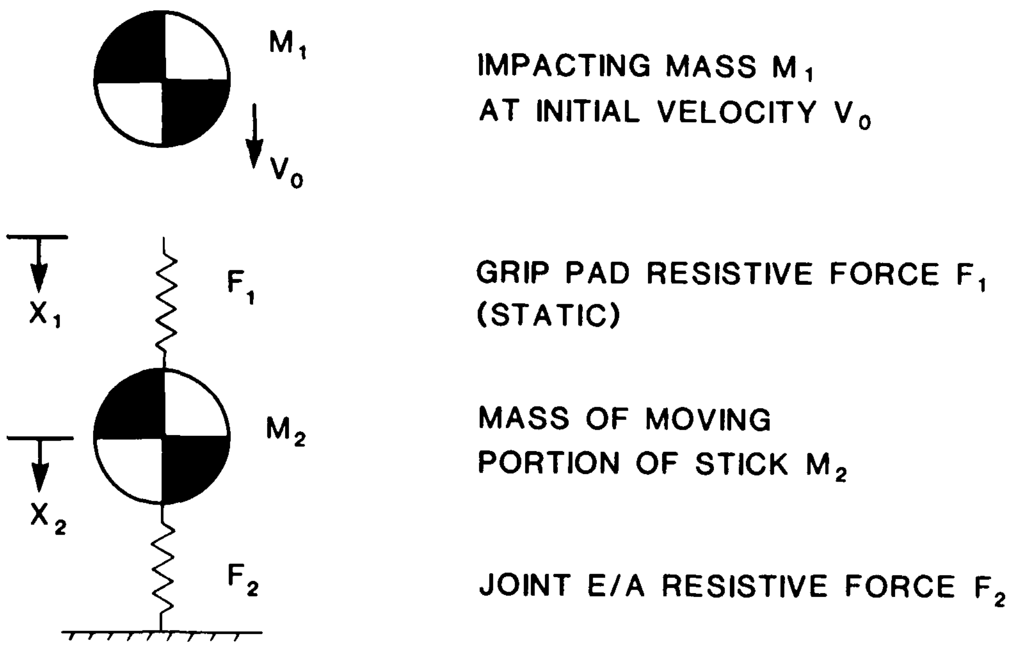


Figure 23. Tab load-limiter development and static test results.



SAMPLE RESULTS:

(CONSTANT F_1 AND F_2, UNLIMITED GRIP PAD CRUSH)

M_1	F_1	M_2	F_2	X_2 (JOINT DISPL)	X_1-X_2 (PAD CRUSH)	t (PEAK LOAD)	V FINAL
75	200	4.2	125	2.52 in.	3.54 in.	.027 sec	17.6 fps
75	200	3.0	125	2.21	3.07	.021	18.1
75	200	3.0	0	1.04	1.08	.009	19.3
75	200	3.0	*	1.22	2.13	.014	18.7
10	200	3.0	125	.92	1.66	.014	11.1

* $F_2 = 125$ for $X_2 \leq .4$ in., $F_2 = 0$ for $X_2 > .4$ in.

Figure 24. Crashworthy cyclic control stick computer model and results.

The tab load-limiter configuration in this computer model shows less crush distance to achieve the same peak load (400 lb) than the wire load-limiter configuration (see Figures 24 and 25).

The computer model was used to predict the results of both the 75-lb pendulum impactor test and the full-scale drop test. The 75-lb weight of the pendulum approximately corresponded to the upper body weight of a 50th-percentile crewmember. This weight was the original estimate made in Reference 1. The latest analysis assumed an impact mass on the order of 13 lb for the drop tests. This would correspond to the head and helmet weight of a 50th-percentile crewmember. Figures 26 and 27 show the force-versus-displacement plot expected for each design, where the impact velocity is assumed to be 20 ft/sec. Here the peak values exceed the 200-lb resistive force shown in Figure 24, the increase being caused by the dynamic stiffness of the foam.

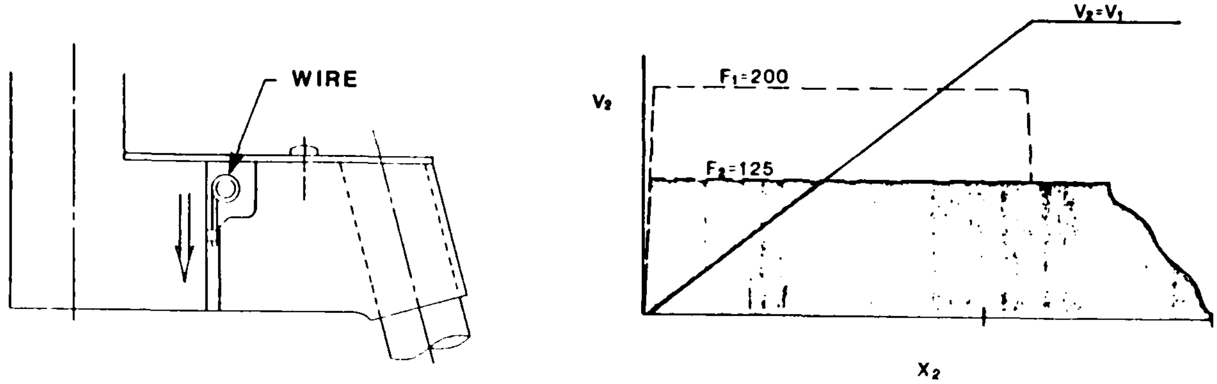
5.6 PROPOSED CONFIGURATIONS

The configurations that were statically and dynamically tested and outlined in this section consist of the following:

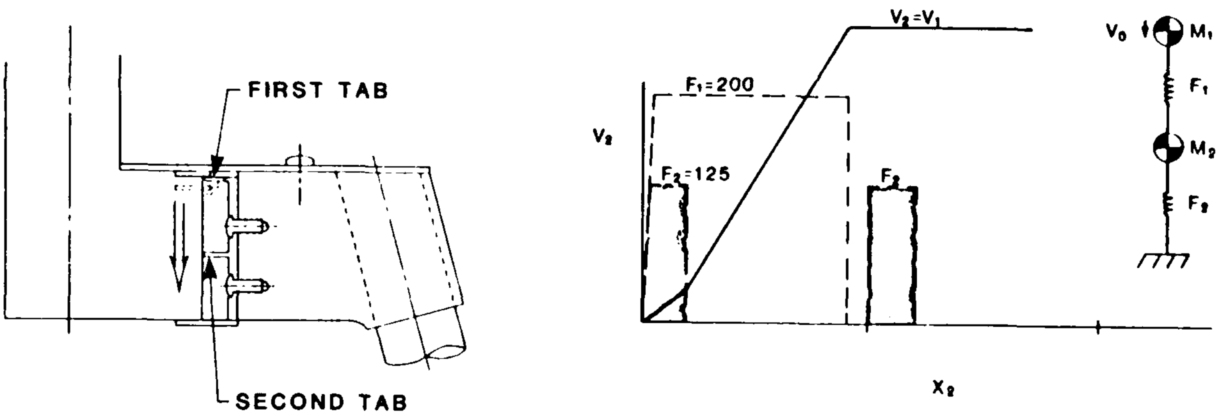
- Design No. 1 - A foam pad, 1.5 in. thick, bonded to the grip; an adjustment mechanism located on the moving portion of the stick; a 5-1/4-in. stub height after separation; a dovetail joint; and a wire to limit the separation loads (see Figure 28).

- Design No. 2 - Same as Design No. 1 except for the use of the tab bender energy absorber to resist joint separation.

A weight breakdown of these two designs and a comparison to the previous crashworthy stick (Reference 1) and the existing UH-60A stick is shown in Table 1. Also, an additional 1 lb of weight could be saved if the newer grip design were used.

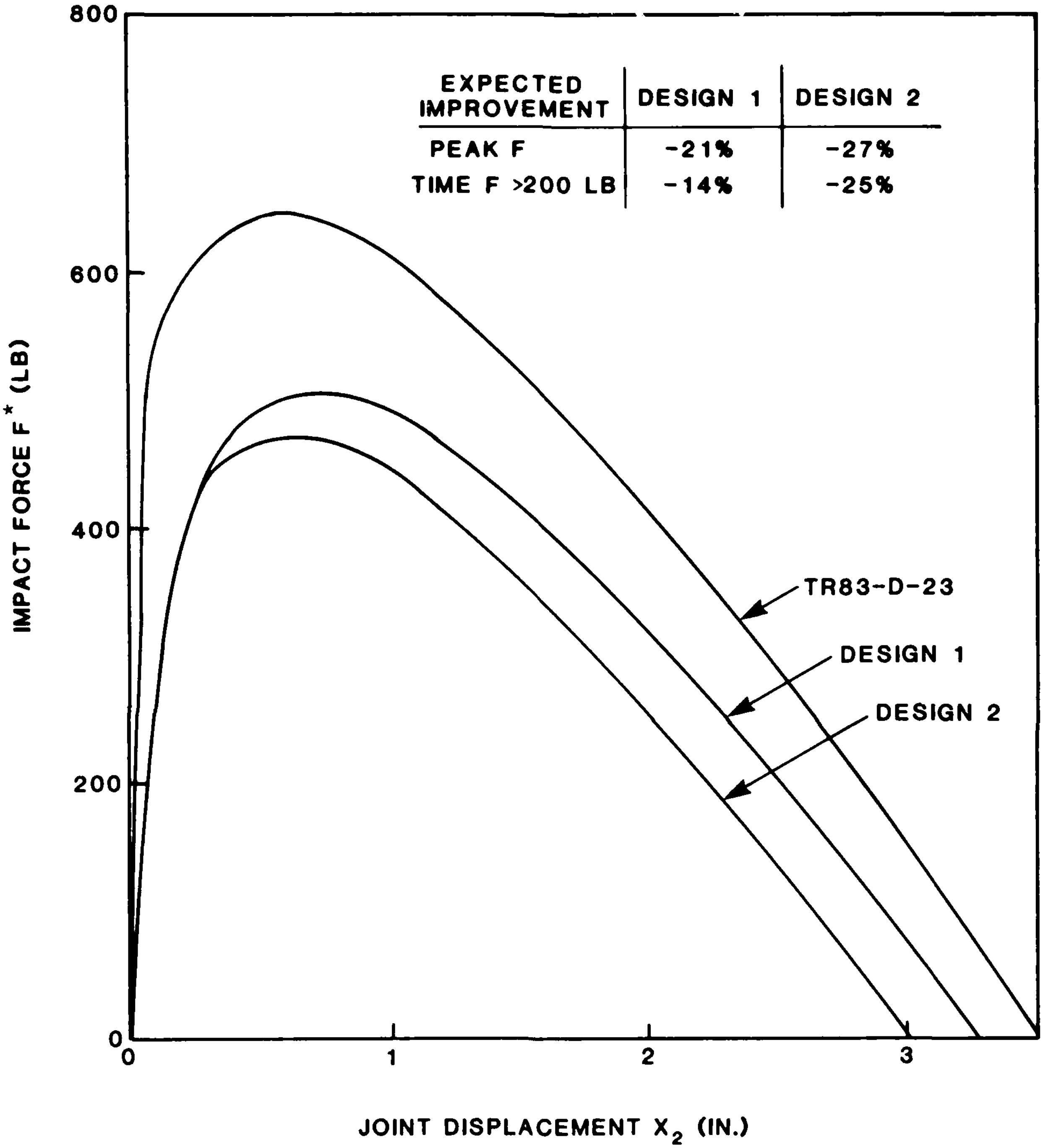


CONFIGURATION 1: WIRE BENDER, STEADY FORCE



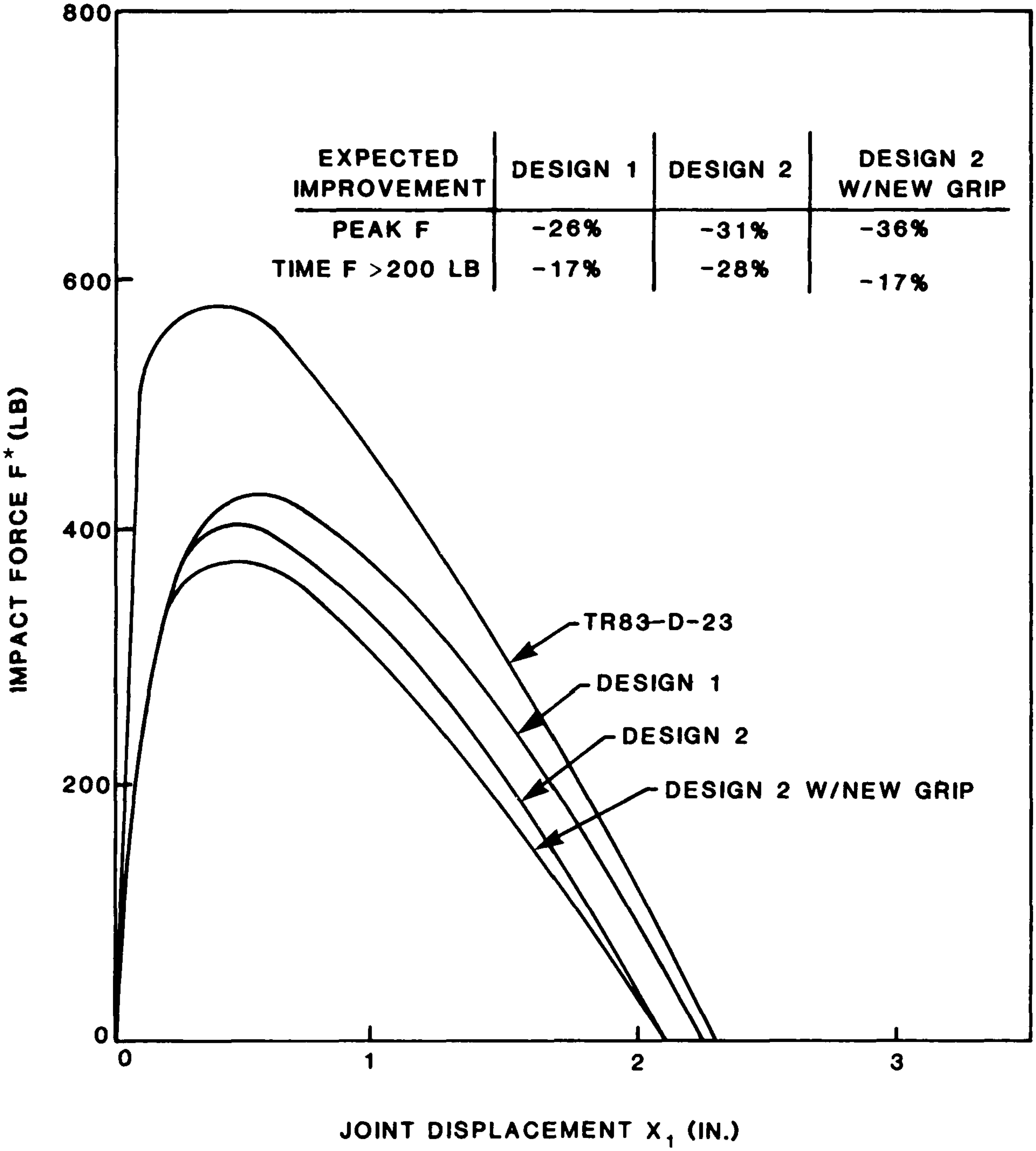
CONFIGURATION 2: TAB BENDER, INTERMITTENT FORCE

Figure 25. Load-limiting characteristics.



* F is the deceleration force of the impacting mass.

Figure 26. Expected performance - 75-lb pendulum impactor.



EXPECTED IMPROVEMENT	DESIGN 1	DESIGN 2	DESIGN 2 W/NEW GRIP
PEAK F	-26%	-31%	-36%
TIME F >200 LB	-17%	-28%	-17%

* F is the deceleration force of the impacting mass.

Figure 27. Expected performance - 14-lb head impactor.

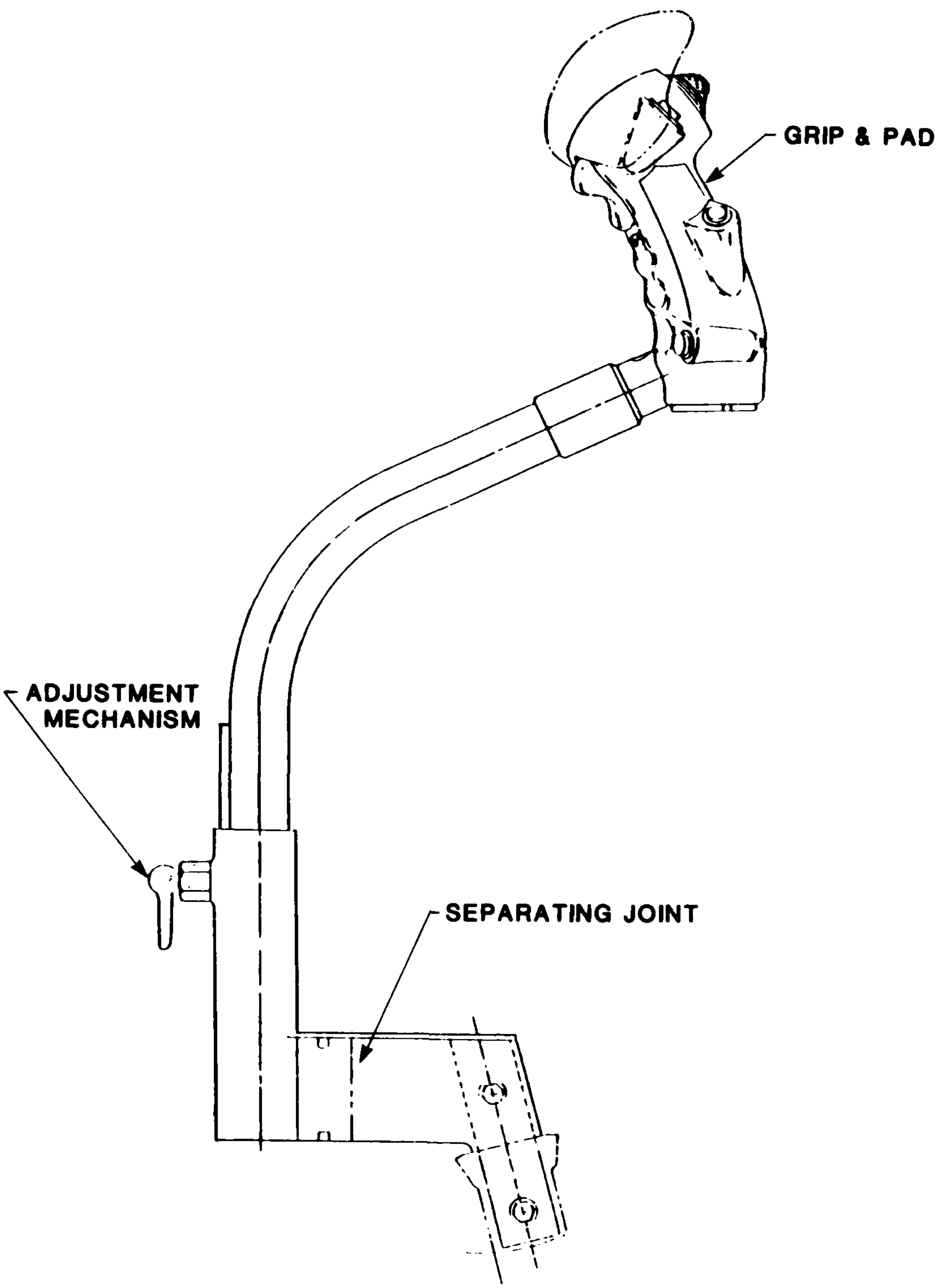


Figure 28. Delethalized cyclic control stick.

TABLE 1. WEIGHT BREAKDOWN OF STICK DESIGN

	Previous	Current		
	TR-83-D-23	No. 1	No. 2	UH-60A
Moving				
Stick	2.23*	1.34	1.34	-
Grip (UH-60A)	1.96	1.96	1.96	-
Total	4.19	3.30	3.33	-
Stationary	1.44	1.45	1.48	2.90**
Total	5.63	4.75	4.81	2.90

*Weights listed in pounds.
**Includes 1.96-lb grip.

6.0 STATIC TESTING

To prove the ability of the crashworthy cyclic control stick to withstand the emergency operational loads specified in Reference 4, static testing was performed on the four test article sticks (Figure 29), two of each design. Tests were performed in the forward, aft, and lateral directions on each of the two designs with loads of 200 lb longitudinally and 100 lb laterally.

Each test article stick was mounted in a rigid test fixture with a socket fitting similar to that of the UH-60A helicopter. This mounting provided a stiff, rigid base for the sticks so that only cyclic control stick characteristics were observed. The base held the sticks in the neutral position, and tests were performed with the height adjustment of the stick at the full-up position.

To place the loads at a specific point (the top of the grip), a grip simulator with the approximate dimensions of the actual grip was constructed of rigid steel tubing. This grip simulator was more rigid than the actual grip to eliminate any grip characteristics from the observed results.

A turnbuckle device was used to apply the load as shown in Figure 30. A strain gage load cell was used to measure forces in the path of the applied load, and a potentiometric displacement transducer was attached to the grip to measure stick deflection. The output of the transducer and load cell was recorded and stored on a digital waveform analyzer and disk memory. (A summary of test instrumentation used in the static and dynamic testing is included in Table 2.) The stick articles were then loaded. Results of the static testing are shown in Table 3.

Posttest inspection of the test articles revealed deformations in the joint set screws (refer to Figure 19). Permanent cyclic stick deflections were traced to the flattening of these set screws. The set screws were replaced with harder screws and a few stick articles were retested. Table 3 shows the retested stick articles and resultant deflections in parenthesis. Results show no visible permanent deflections. The new stick articles supported emergency operational loads per Reference 4 without permanent deformation.

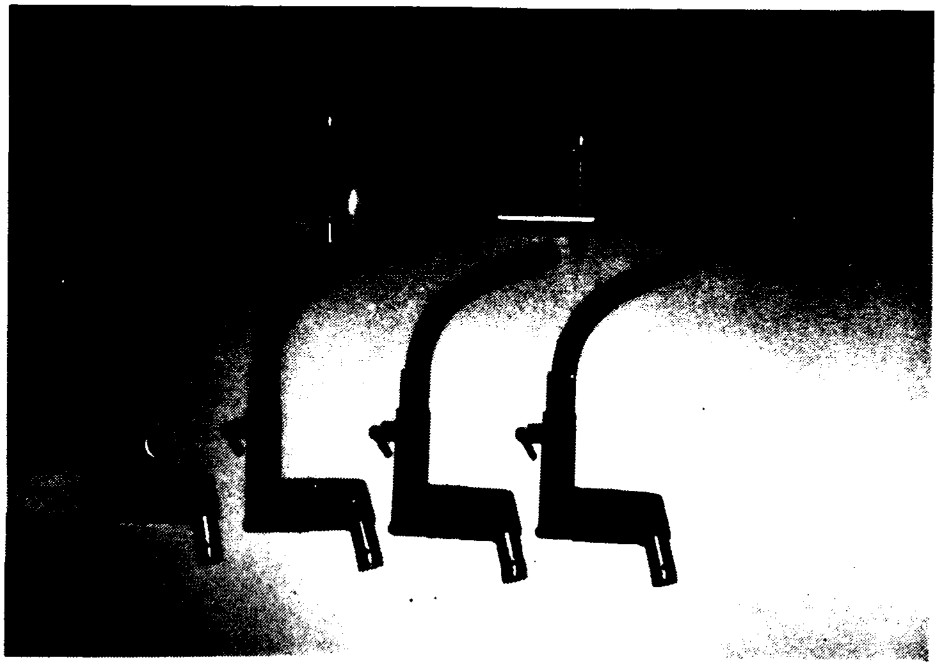


Figure 29. Four test articles.

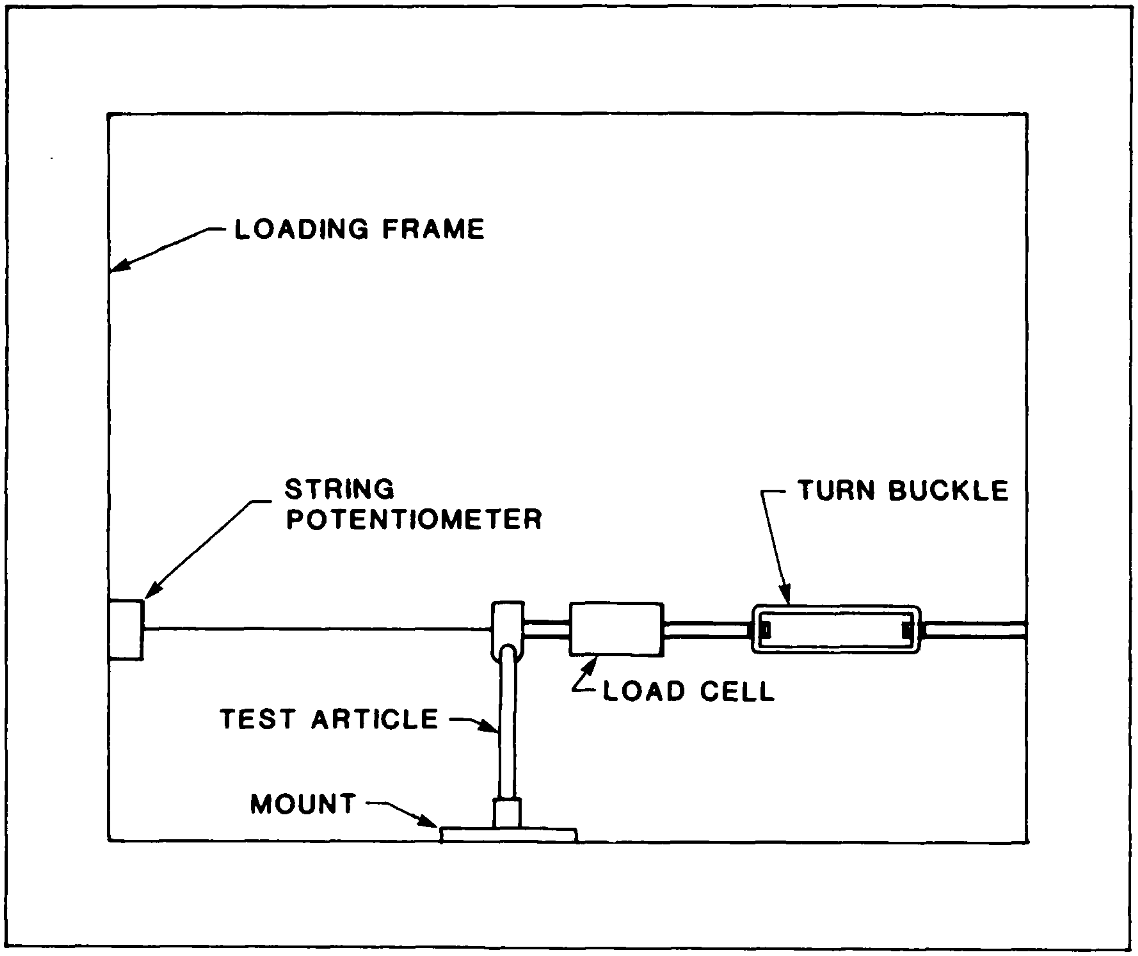


Figure 30. Operation and destructive test configuration.

TABLE 2. STATIC AND DYNAMIC TEST INSTRUMENTATION

Item	Instrument	Type	Manufacturer	Model	Range	Response	Accuracy Full-Scale (percent)
1	Load Cell	Strain Gage	Interface	1210-AO-2K	2000 lb	NA	0.1
2	Displacement Transducer	Potentiometric	Celesco	PT-101-10C	10 in.	100 G	0.1
3	Signal Conditioner	Bridge Offset	Bell & Howell	1-183	±1 V	DC to 30 kHz	0.1
4	Digital Voltmeter	Digital	Valhalla	4440	±2 V	NA	0.05
5	Accelerometer	Unbonded	Bell & Howell	4-202	100 G	1250 Hz	0.75
6	Waveform Analyzer	Digital	Norland	3001	±100 mv to 100 v DC to 60 kHz	Flat within 0.5% from	0.75
7	Tape Recorder	Analog	Sangamo	Sabre VI	1 V RMS	2500 Hz	0.4
8	High-speed Motion Picture Camera	Locam	Redlake	51	500 fps	NA	NA

TABLE 3. OPERATIONAL TEST RESULTS

Design*	Sample	Longitudinal Deflection at 200 lb. (in.)	Lateral Deflection at 100 lb. (in.)
No. 2	S/N 1	3.8 F**	1.8 (1.6)
No. 2	S/N 2	3.6A (3.3A)	1.9
No. 1	S/N 3	3.6 F	1.7
No. 1	S/N 4	3.4A (3.8F)	1.8

*Design No. 1 - wire load limiter, Design No. 2 - tab load limiter.

**"F" is for forward, "A" is for aftward, figures in parenthesis refer to retest after replacement of failed set screws.

7.0 DYNAMIC TESTING (PENDULUM)

The objectives of the pendulum test were to demonstrate the dynamic function of the crashworthy cyclic control stick, to determine the best of the two designs, and to compare relative improvements with the previous design reported in Reference 1.

The test apparatus was identical to that used previously, so results were directly comparable. Figure 31 shows the apparatus, which includes a grip simulator to which the foam pad is bonded. The grip simulator retains the actual weight of the UH-60A baseline grip and can be modified to simulate the weight of the newer grip.

The stick articles were adjusted to the neutral vertical position. Acceleration-versus-time plots are shown in Figure 32 for all four tests. Table 4 gives maximum values and variations in the grip weight and foam density for comparison. Conversion from acceleration to force was done with the formula: F(lb) = 75 x G, where F is the force acting on the grip end of the stick, 75 is the weight in lbs of the pendulum, and G is the measured acceleration of the pendulum head. In Figure 32 and Table 4, S/N 1 and S/N 2 correspond to the wire load-limiter design. S/N 3 and S/N 4 correspond to the tab load-limiter design. For the wire load-limited samples, the grip mass was varied to show differences in peak load. Foam pad density was varied for the tab load- limiter samples which also showed peak load variations.

Each crashworthy cyclic control stick performed as expected, with a positive separation. All the data traces show small differences. Those differences are believed to be caused by load resisting characteristics, foam pad density, and inertial weight.

Peak loads ranged from 420 lb to 495 lb, with a 17-msec to 19-msec base. Comparisons between these results and those reported in Reference 1 are shown in Figure 33 and Table 5. Relative to the first crashworthy stick, peak accelerations in the new stick were reduced by 63 percent.

TABLE 4. PENDULUM TEST RESULTS

Design	Sample	Peak* Load (lb)	Duration (msec)	Weight (lb)	Foam Pad Density (lb/ft^3)
Tab	No. 1	472	19.0	3.33	5.2
Tab	No. 2	493	18.0	3.33	5.8
Wire	No. 3	435	18.0	3.30	6.1
Wire	No. 4	420	17.5	2.79**	6.1

*Obtain by multiplying G values by 75-lb pendulum weight.
**Weight using new grip.

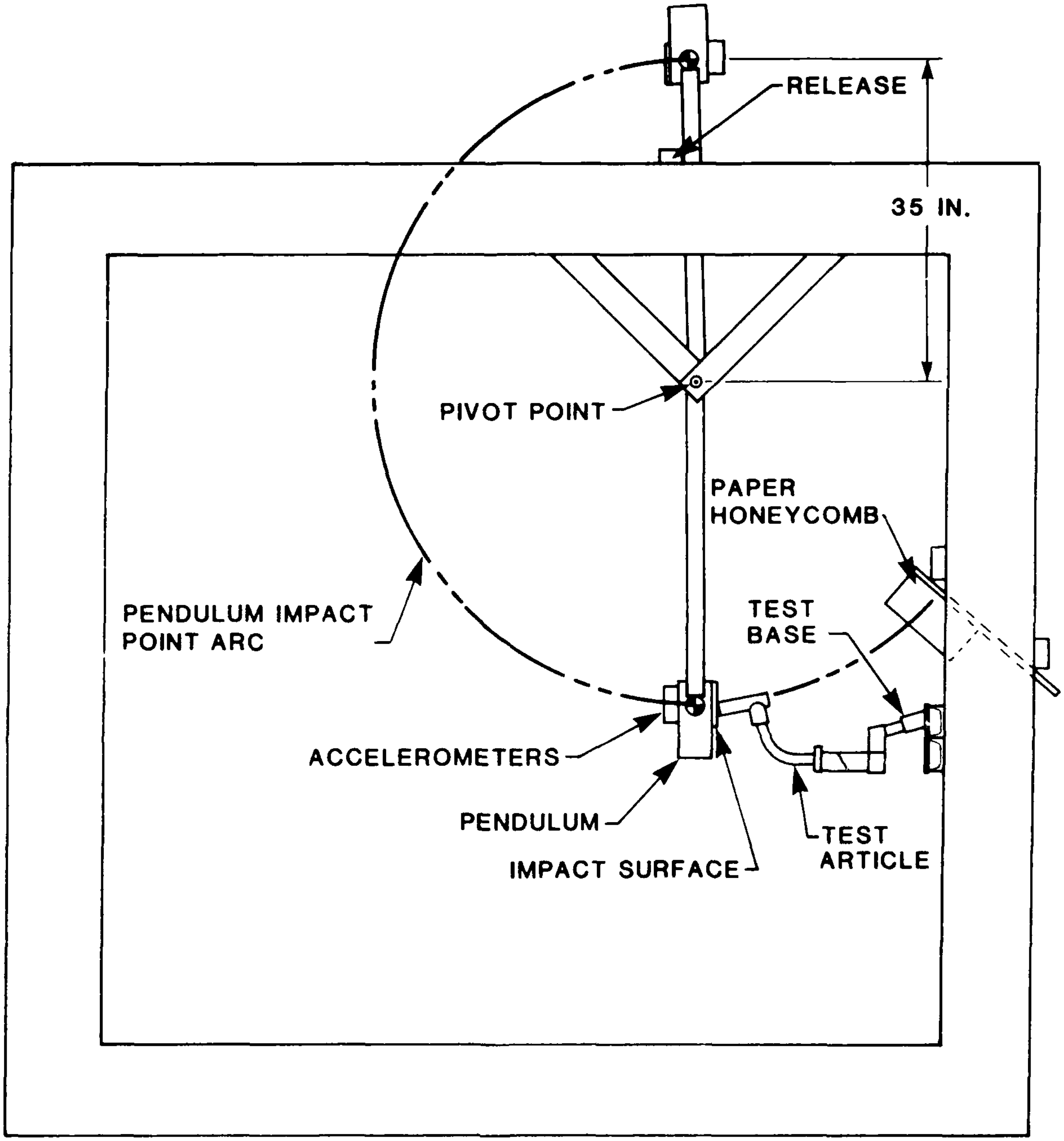


Figure 31. Dynamic pendulum test configuration.

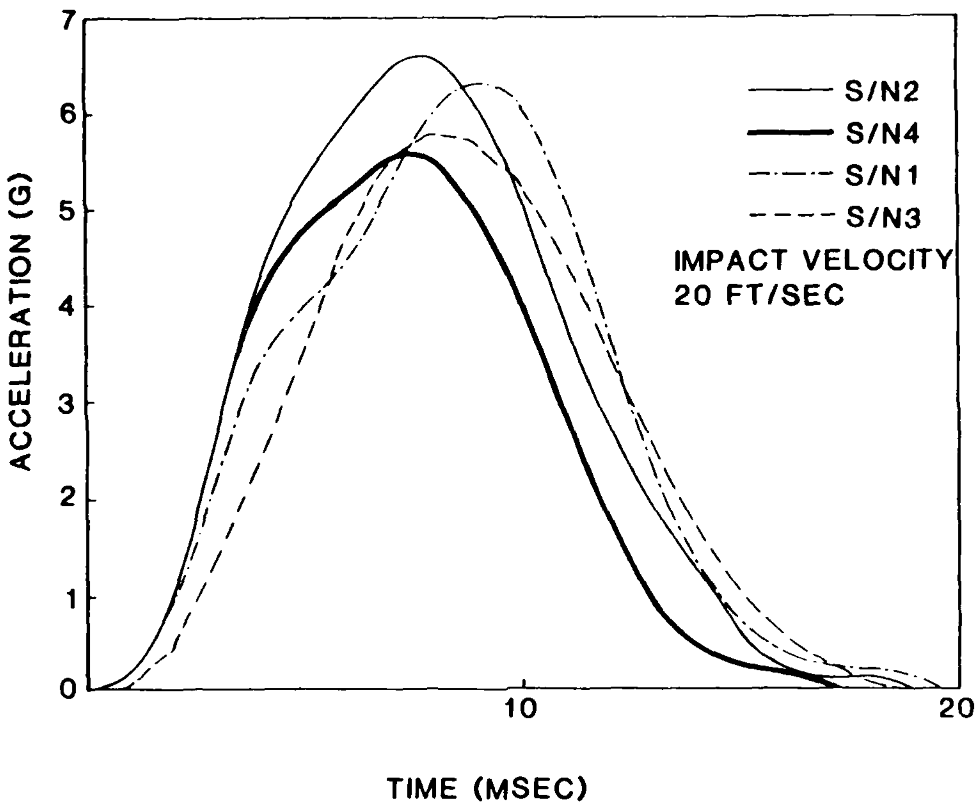


Figure 32. Pendulum test results.

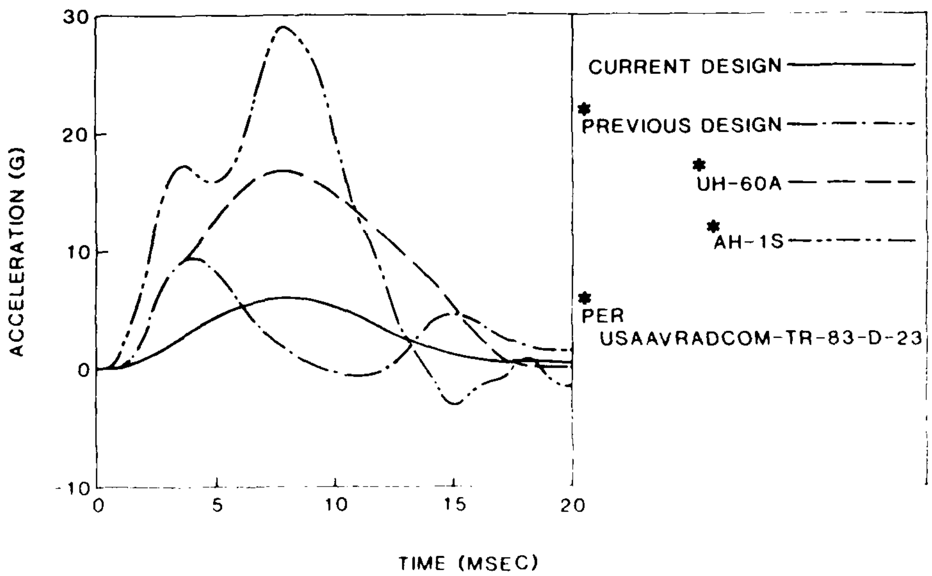


Figure 33. Pendulum test - direct comparison.

TABLE 5. PEAK AND DURATION VALUES FOR ALL TESTS

Stick	Peak (G)	Duration (msec)
Current*	5.7	17.8
Previous**	9.3	8.3
UH-60A	16.7	17.2
AH-1S	29.1	13.7

*Average values of wire load-limiter design.
**Average values of four samples (Reference 1).

8.0 DESTRUCTIVE STATIC TESTING

The procedure for destructive testing was identical to the operational tests. The test articles, rebuilt from pendulum test residue, were adjusted to maximum vertical position and loaded as before. In the longitudinal direction, a margin of safety of 33 percent was reached at failure of a race insert within the joint. The wedged race, which has two rectangular pins at each end and is pressed into the aluminum fitting, failed by shearing a pin (refer to Figure 19). In the lateral directions, no failure occurred due to space limits in the test fixture. A margin of safety of 400 percent had been reached before the test was terminated.

9.0 EVALUATION AND DESIGN IMPROVEMENTS

9.1 DESIGN IMPROVEMENTS

As mentioned in Section 6.0, the set screws which preloaded the joint were replaced. The problem was the bearing strength of the set screws. Deformation of the screw tips caused the joint to loosen.

Another improvement, which came about after the pendulum tests, is the reduction in foam pad density. After reviewing the high-speed films and test residue, the foam pads did not appear to crush as expected. The dynamic effect on the stiffness of the pad was apparently underestimated. Further dynamic tests were performed on the grip pads (see Figure 34) with results showing a 30-percent reduction in density required to achieve the desired dynamic stiffness. The new grip pad design (4.5 to 5.0 lb/ft^3) was implemented for the full-scale drop tests that followed.

9.2 EVALUATION

The static tests showed little difference between the two designs tested; however, in the pendulum tests, there were marked differences. Design No. 1, the wire load-limiter, appeared to be advantageous with lower peak loads. It was hoped that Design No. 2, the tab load-limiter, would react less force due to its intermittent load design. However, this was not the case; it is speculated that the higher peak loads were due to binding of the joint. This explanation is supported by gouges on the inside of the aluminum fitting. It is believed that the tabs caused the fitting to rotate into the walls of the clawfitting of the tab load-limiter samples. This was not seen on the wire load-limiter samples. Design No. 1 was selected for further testing. This decision was made based upon the above described performance and the anticipation that Design No. 1 could be produced somewhat more economically.

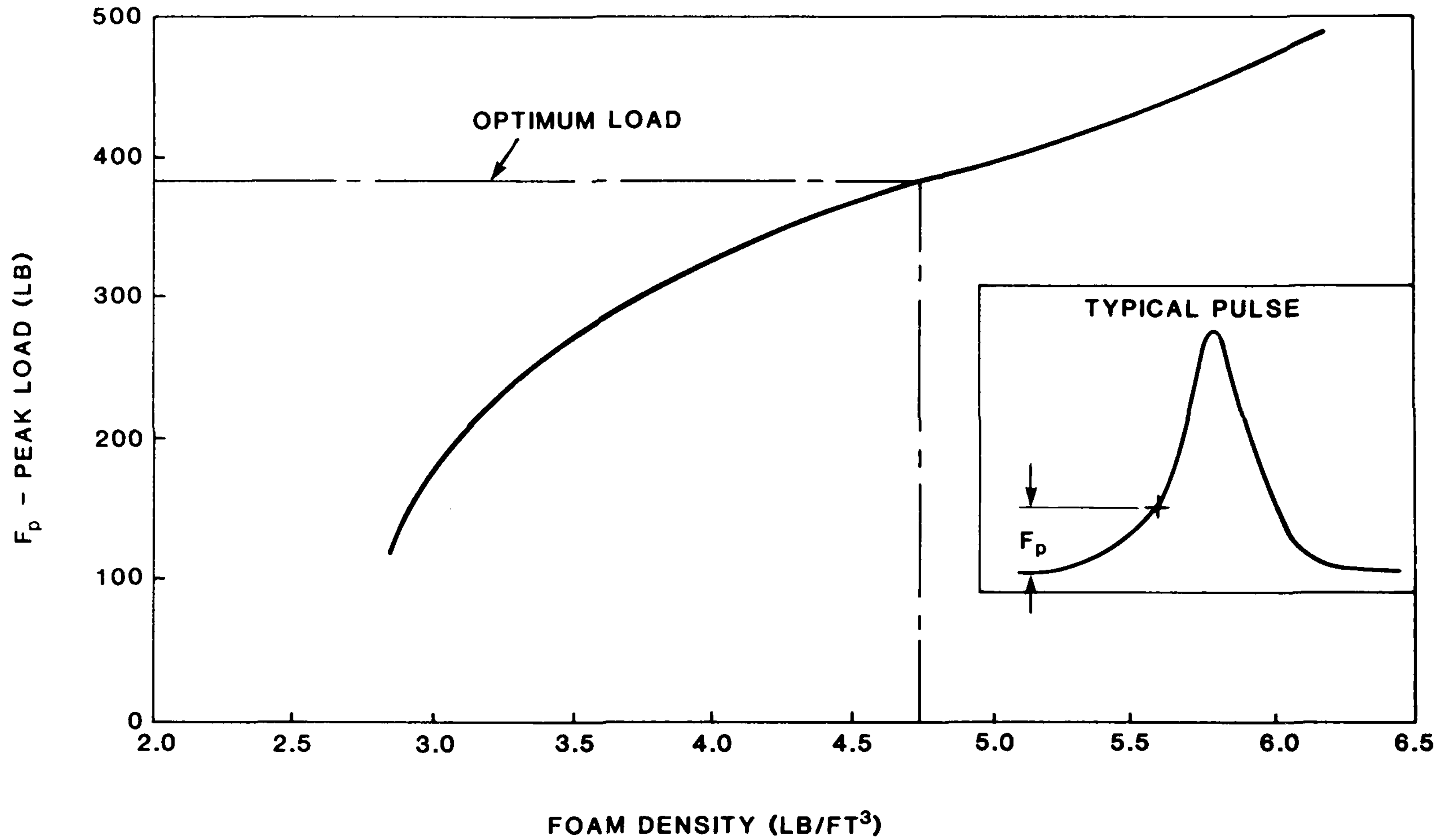


Figure 34. Dynamic testing of foam pad.

10.0 FULL-SCALE DROP TESTING

All dynamic testing performed previous to full-scale testing has demonstrated the relative crashworthiness of each design. Full-scale testing, on the other hand, has attempted to show the actual severity of the situation. In these tests, two test articles of the current selected crashworthy cyclic control stick design and one UH-60A cyclic control stick were tested in combination with a stroking UH-60A energy-absorbing crewseat.

10.1 APPARATUS AND SETUP

All the tests were conducted with a 50th-percentile Hybrid III dummy representative of a basic 50th-percentile Army aviator in weight and size. An actual SPH-4 Army aviator helmet weighing 3.6 lb was worn by this dummy in all tests.

The UH-60A energy-absorbing seat and the crashworthy cyclic control stick were mounted on a frame fixed at 32.5-degree pitch, with respect to the horizontal. This angle was shown by program SOM-LA to give the highest probability of occupant/stick impact. A pretest photograph of the drop cage is shown in Figure 35.

Instruments used in this series of tests are listed in Table 6. The anthropomorphic dummy was instrumented with accelerometers located in the head, thorax, and pelvis in the vertical, longitudinal, and lateral directions (local coordinate axes). In addition to the accelerometers, a six-axis load cell was used in the neck of the dummy.

Accelerometers were placed on the drop cage to measure vertical input pulse and on the seat bucket to measure decelerations in the direction of seat stroke.

For added cyclic stick performance data, three single-axis load cells were mounted in tripod fashion about the base of the stick. Figure 36 shows the orientation of the measuring devices.

The signals were amplified by signal conditioning equipment and recorded on magnetic tape.

10.2 PROCEDURE

Prior to actual testing, a series of preliminary drops were made to shape the input pulse. The drop cage was weighted to simulate fixtures, equipment, and stroking mass during energy absorption of the seat. The pulse was shaped by a pyramid stack of paper honeycomb, where the area of the honeycomb is proportional to deceleration. The total velocity change of the pulse includes rebound of the cage off the honeycomb stack. The desired pulse was to give a 48-G peak with a base of 65 msec and a 50-ft/sec velocity change. The UH-60A crashworthy crewseat limitations and the desire for the best probable strike were the constraints associated with choosing the pulse shape.

The UH-60A energy-absorbing seat was mounted on the cage in a neutral, longitudinal position for the first three tests. On the fourth test (second test

TABLE 6. FULL-SCALE DROP TEST INSTRUMENTATION

Item	Instrument	Type	Manufacturer	Model	Range	Location
1	Accelerometer	Piezo resistive	Endevco	7232C-750	100 G	Dummy's Head
2	Accelerometer	Piezo resistive	Endevco	7232C-750	100 G	Dummy's Head
3	Accelerometer	Piezo resistive	Endevco	7232C-750	100 G	Dummy's Head
4	Accelerometer	Strain Gage	Bell & Howell	4-202	50 G	Dummy's Thorax
5	Accelerometer	Strain Gage	Bell & Howell	4-202	50 G	Dummy's Thorax
6	Accelerometer	Strain Gage	Bell & Howell	4-202	50 G	Dummy's Thorax
7	Accelerometer	Strain Gage	Bell & Howell	4-202	100 G	Dummy's Pelvis
8	Accelerometer	Strain Gage	Bell & Howell	4-202	100 G	Dummy's Pelvis
9	Accelerometer	Strain Gage	Bell & Howell	4-202	100 G	Dummy's Pelvis
10	Accelerometer	Strain Gage	Bell & Howell	4-202	100 G	Seat Bucket
11	Accelerometer	Strain Gage	Bell & Howell	4-202	100 G	Seat Bucket
12	Accelerometer	Strain Gage	Bell & Howell	4-202	100 G	Seat Bucket
13	Accelerometer	Strain Gage	Bell & Howell	4-202	100 G	Cage
14	Accelerometer	Strain Gage	Endevco	7232C-750	100 G	Cage (Redundent)
15	Load Cell	6 Axis/Strain Gage	Denton	1716	2000-3000#	Dummy's Neck
16	Load Cell	Strain Gage	Interface	1210-A0	10 K	Cyclic Stick
17	Load Cell	Strain Gage	Interface	1210-A0	10 K	Cyclic Stick
18	Load Cell	Strain Gage	Interface	1210-A0	10 K	Cyclic Stick
19	Displacement Transducer	Potentiometric	Celesco	PT-101-30C	30 in.	Seat

Existing UH-60A Stick

Figure 35. Drop test configuration.

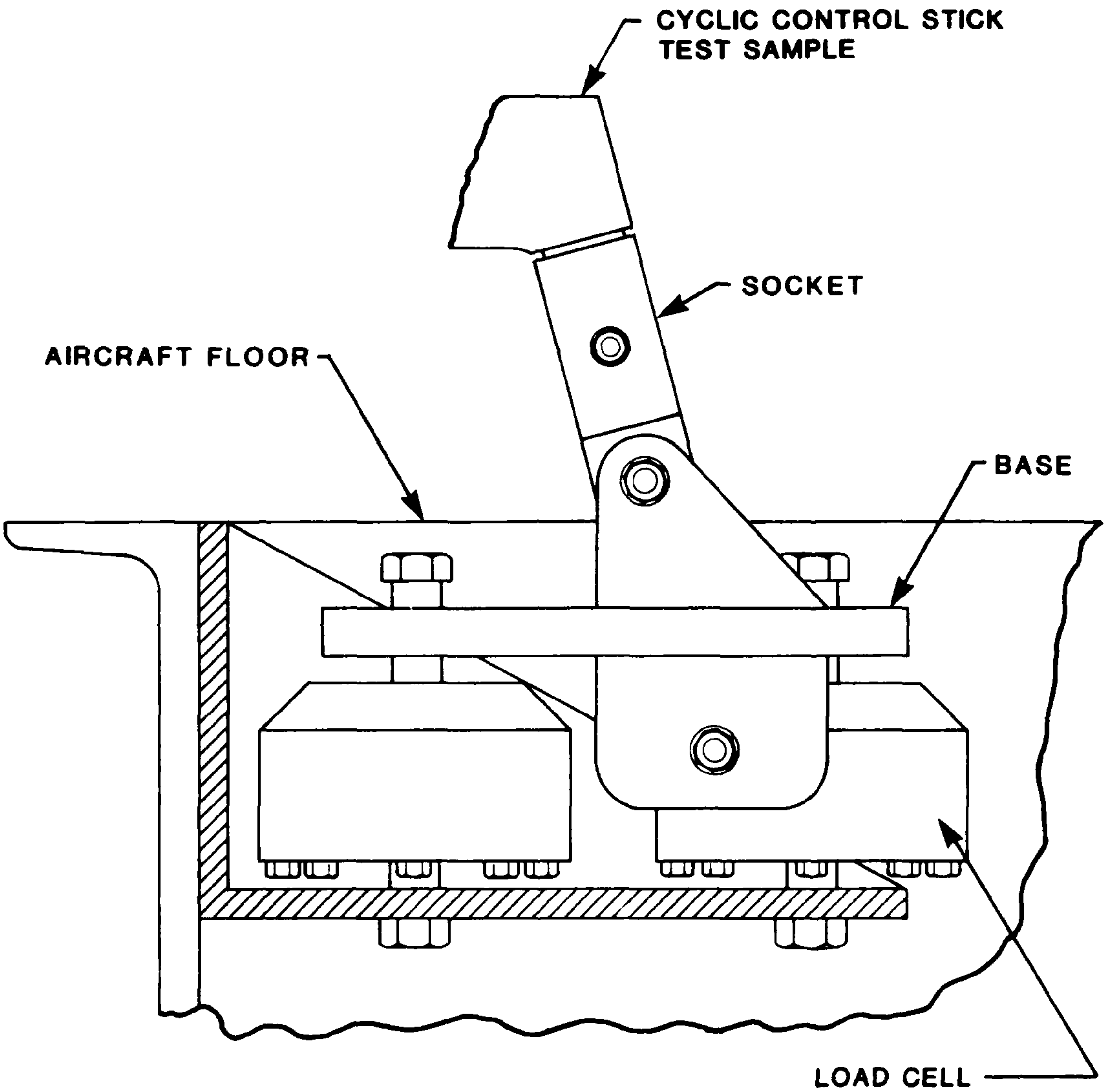


Figure 36. Cyclic stick load measuring and mounting fixture.

of the Black Hawk stick), the seat was moved aft 5/8 of an inch. This was done to assure a different strike location on the dummy which, on the second test, struck the neck. The cyclic control stick samples were fixed in neutral pitch and adjusted to neutral vertical position for best strike probability.

The anthropomorphic dummy was restrained with the inertia reel in the unlocked position. The feet were lightly taped to simulated rudder pedals to control the initial position of feet and legs.

After final checks were made, the cage was lifted to the height determined during calibration of the honeycomb stack, and released.

10.3 TEST RESULTS

Posttest views of the high-speed film show head and/or neck impacts for all tests. Two drop tests were made using the crashworthy stick design and two were made using the same UH-60A stick. The crashworthy sticks separated as intended and the UH-60A stick stayed rigid with some bending which left a 1/2 in. permanent deflection vertically.

Figure 37 shows the input pulse, shaped by the honeycomb pyramid, with peak acceleration as intended, but a slightly lower velocity change of 47 ft/sec was seen. A velocity change of 48 to 50 ft/sec was expected and reached during the calibration drops.

In the acceleration-versus-time and force-versus-time plots in Figures 38 through 41, head (neck) to stick impact flags are shown on each plot. All plots refer to test numbers where Test No. 1 and 3 are the crashworthy cyclic control stick articles and Test No. 2 and 4 are the UH-60A Black Hawk article.

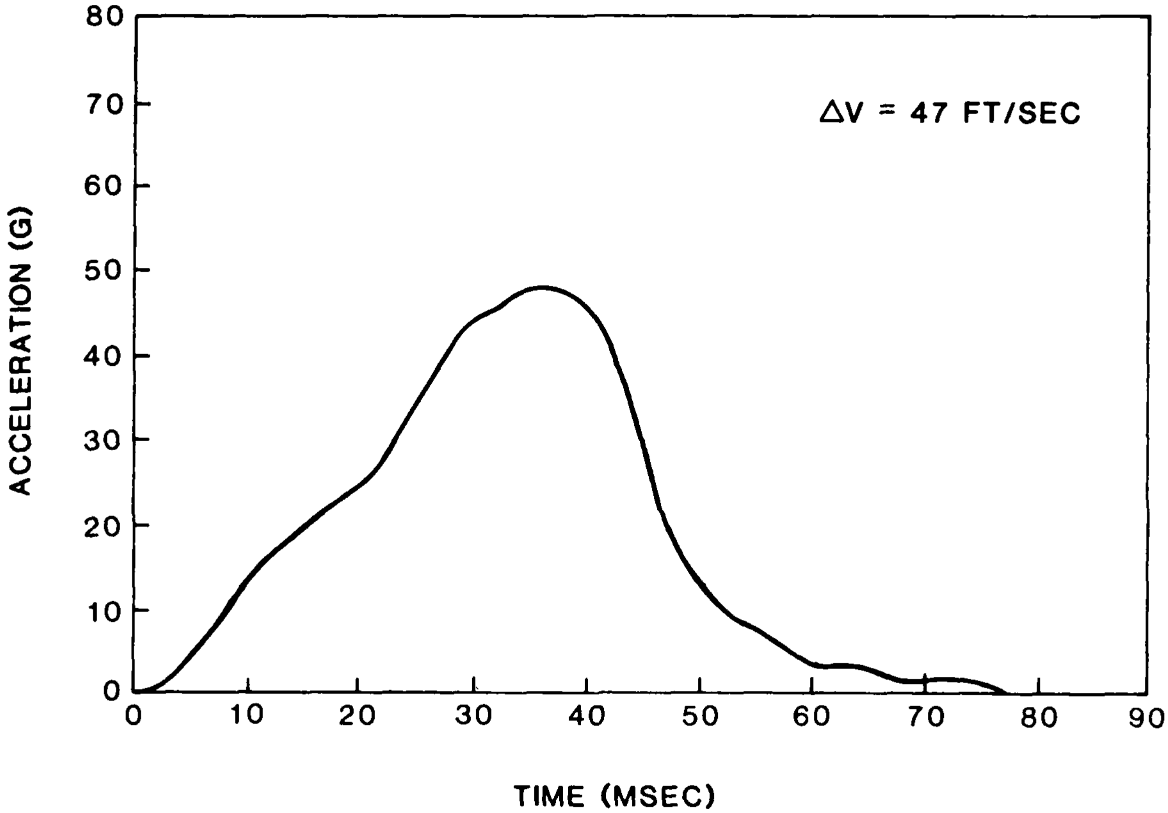


Figure 37. Input pulse - drop tests.

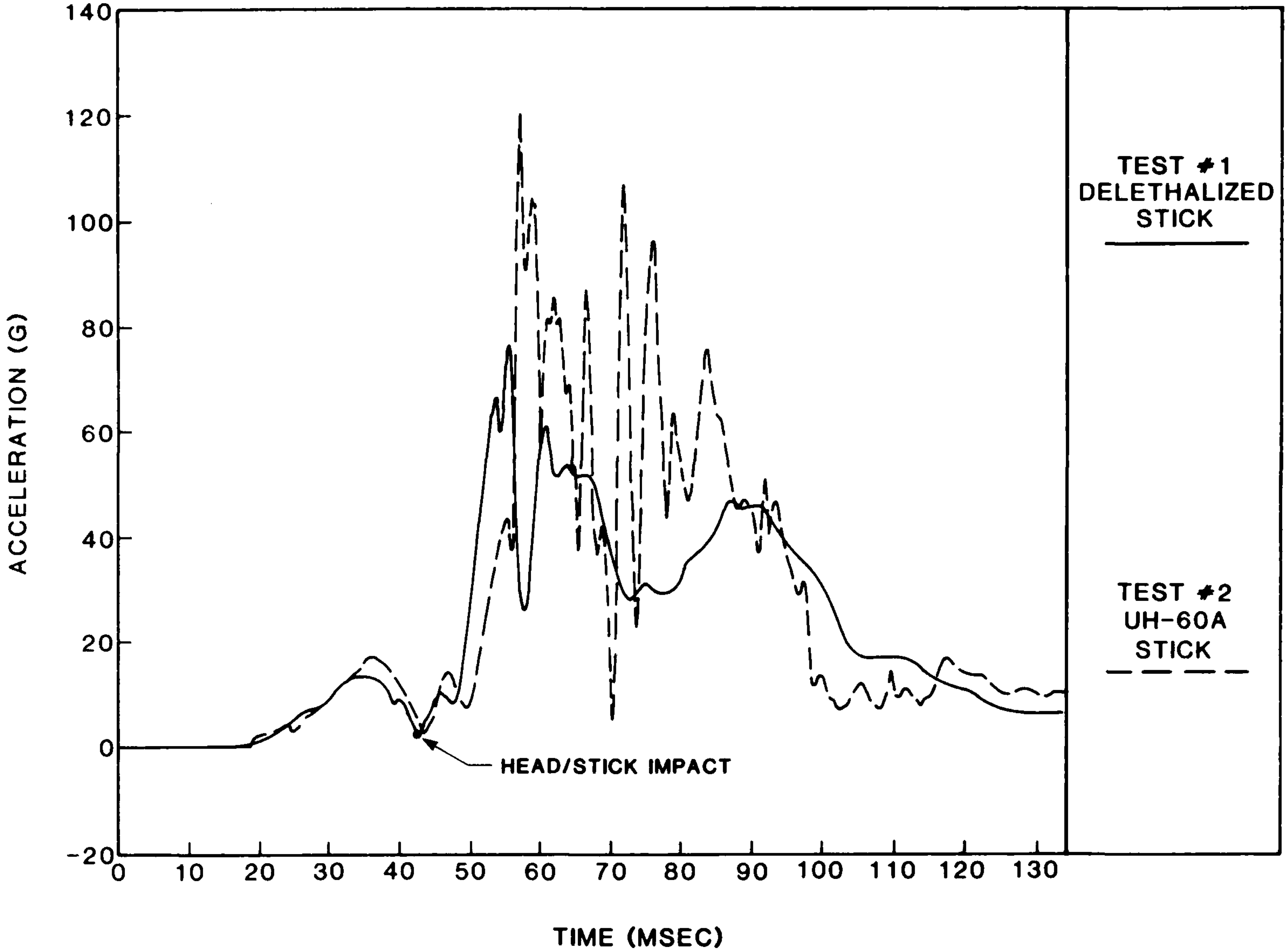


Figure 38. Head accelerations, resultants, test nos. 1 and 2.

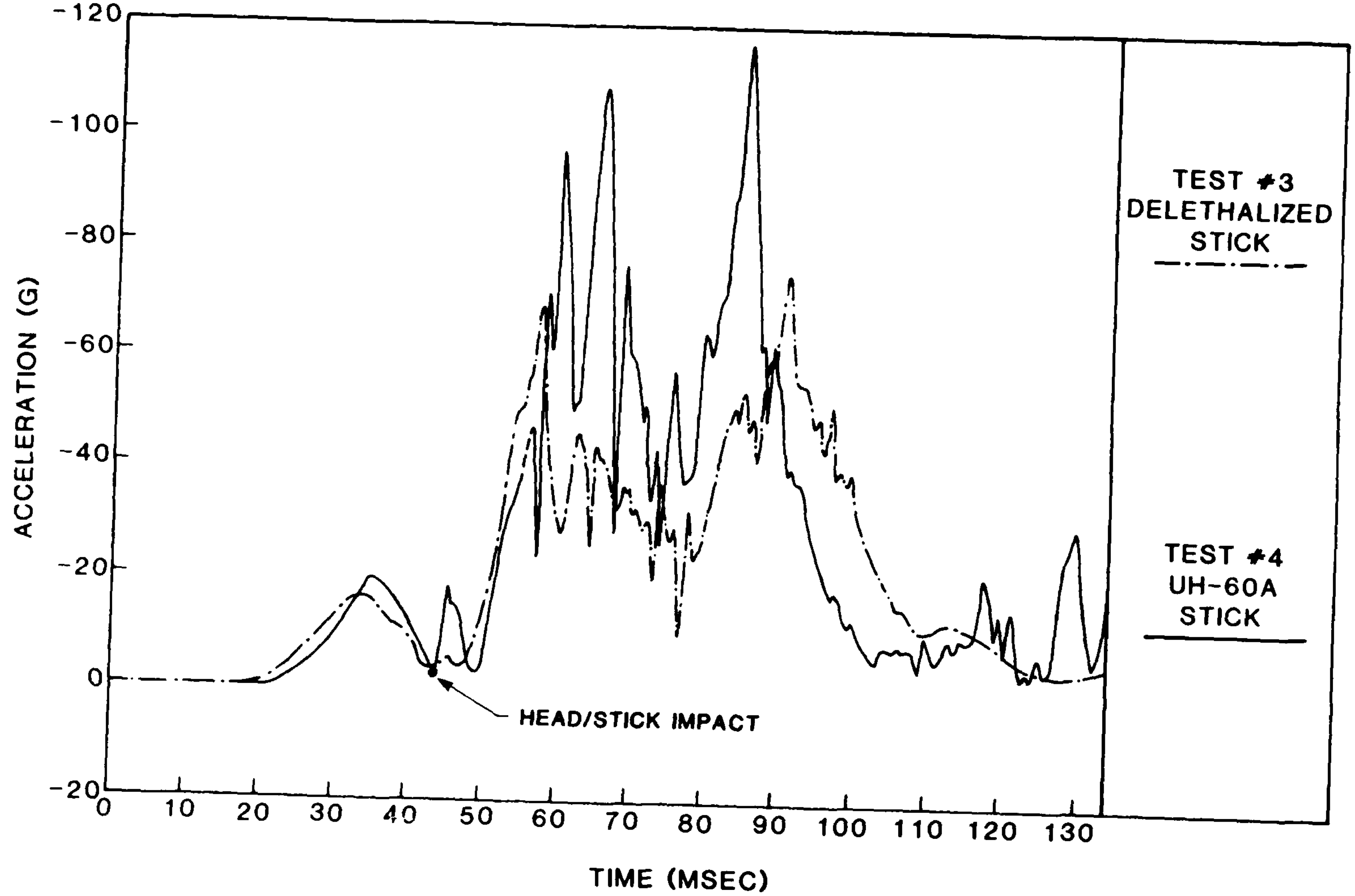


Figure 39. Head accelerations, resultants, test nos. 3 and 4.

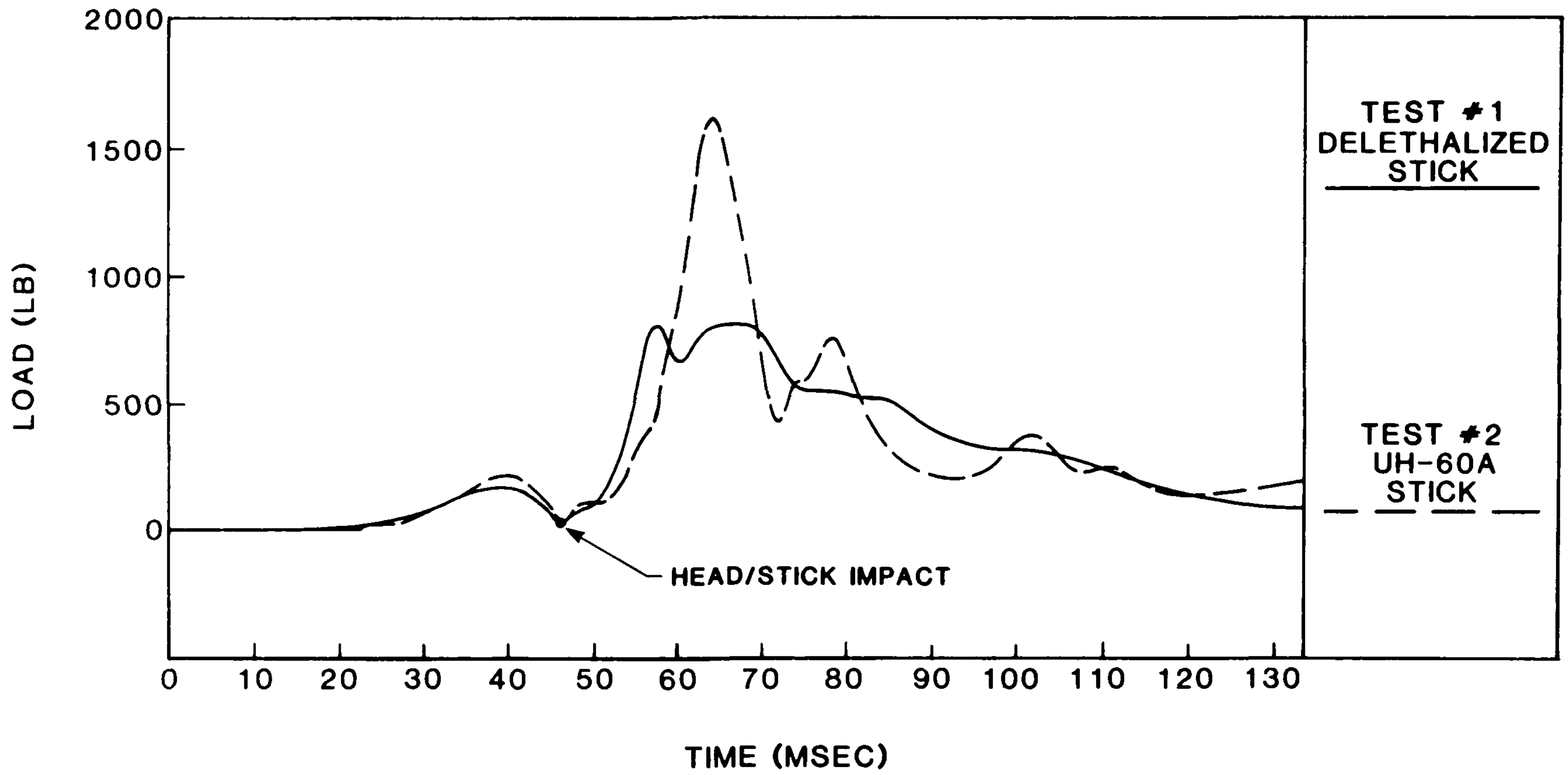


Figure 40. Neck loads, resultants, test nos. 1 and 2.

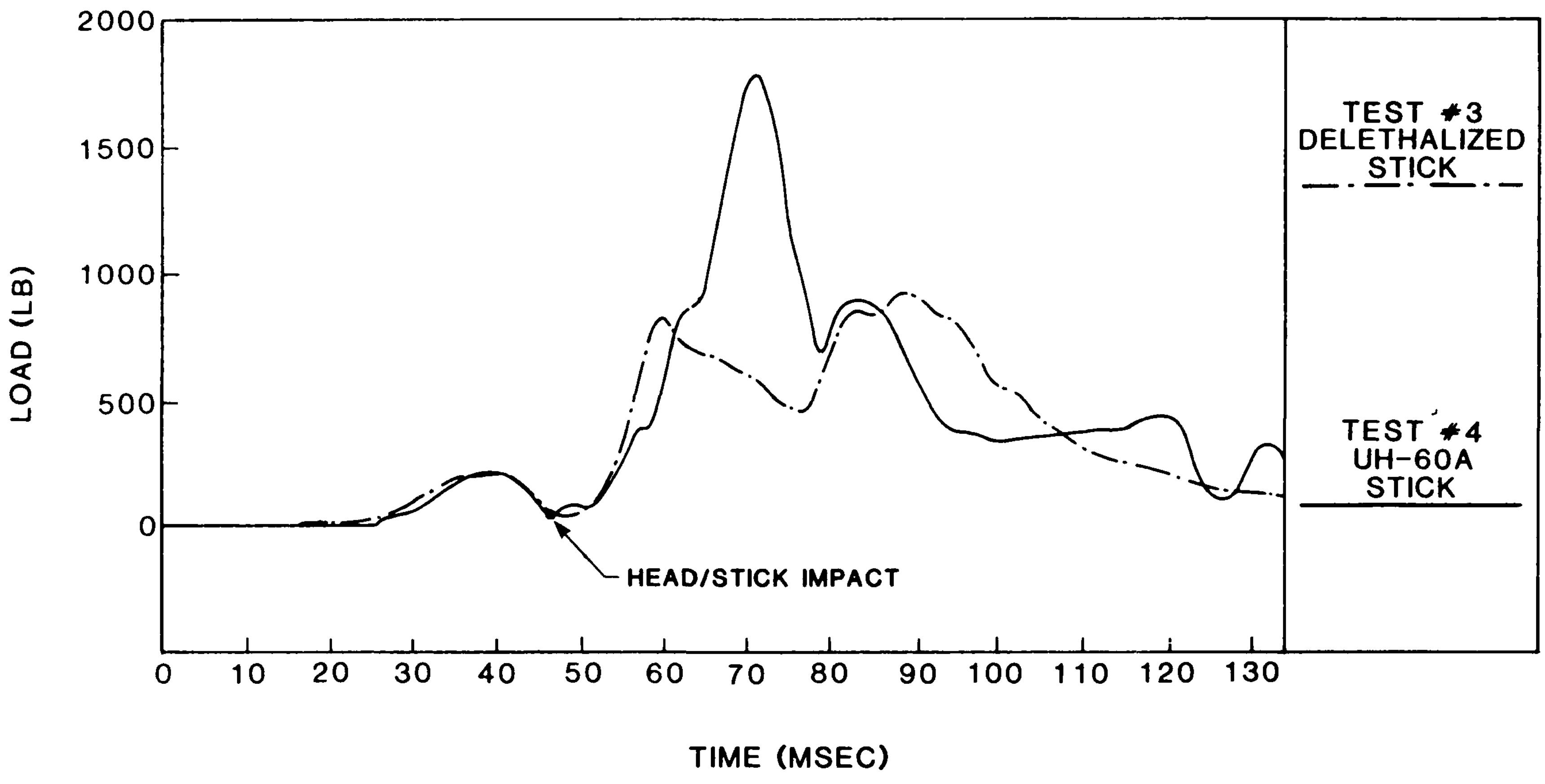


Figure 41. Neck loads, resultants, test nos. 3 and 4.

11.0 DISCUSSION OF PERFORMANCE

Although the crashworthy cyclic control stick designed and tested during this program functioned as intended, it was and is difficult to minimize the impact loads. Since there are many different crash scenarios, the head and neck impact velocities are variables complicating the selection of a single impact velocity which is needed for optimization. During the design phases, Program SOM-LA was used to determine the most likely impact velocity. As shown in Figure 42, the velocity varies from 0 to 30 ft/sec. As mentioned in Section 2.0, program SOM-LA predicted an impact at .080 msec. for a 50th-percentile occupant under the drop test conditions, but in posttest analysis of the high-speed films, the actual impact velocity ranged from 33 to 40 ft/sec. This disagreement in impact velocities is attributed to a change in the initial position of the dummy's head and upper body. This change in the upper body position was a result of the 32.5-degree pitch angle and the inertia reel in the unlocked position. Figure 43 shows the effect of head impact velocity on peak impact load as analyzed by the computer model of the cyclic control stick system. Here, a velocity change from 20 to 30 ft/sec results in an increase of 30 percent in reaction load on an occupant during a crash.

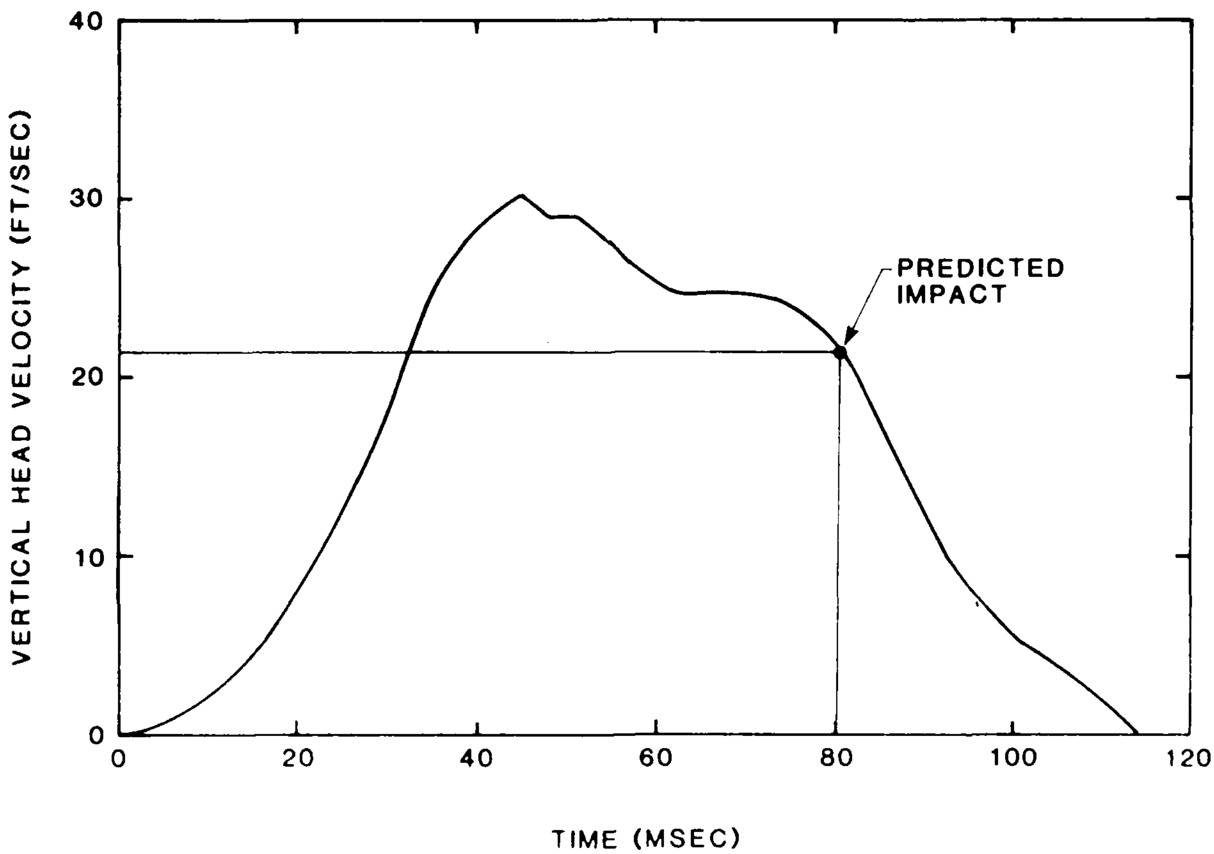


Figure 42. Head velocity - vertical component SOM-LA.

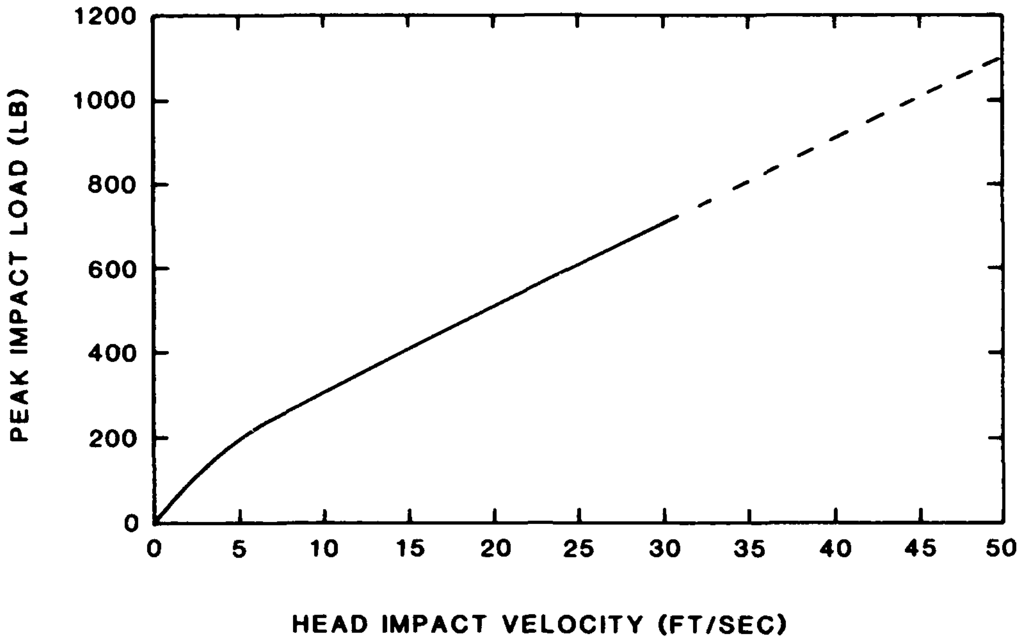


Figure 43. Effect of head impact velocity on peak load impact.

11.1 RELATIVE STICK PERFORMANCE

Analysis of stick load data (see Figures 44 and 45) shows a marked difference in readings from the two sticks. These measurements are taken from just below the cyclic stick mounting fixture. It must be noted that these plots only show data beginning at the time of stick impact. The data before stick impact only showed traces of the inertial mass of the stick and fixture and therefore was omitted. Component plots from the stick load cells are shown in Appendix C for the forward, lateral, and downward directions.

The plots of resultant stick load show a relatively low load just after impact of the crashworthy stick. This low load can be explained as the stroking force of the separating stick. After stick separation, one would expect the load to drop. This can also be seen on the plots. The traces from the stick load cells do not show actual impact loads imposed on the occupant, because of the inertial loads acting on the stick and fixtures. However, these other inertial loads were estimated to be less than 200 lb.

The grip pads performed as predicted; complete crush was evident in the posttest inspection of parts.

11.2 HEAD INJURY

The reduction of head and neck injury is the primary objective of this program. Although only certain parts of the face and neck were impacted in this series of tests, all other areas were considered as possible targets because of varying sizes of occupants, seating positions, and cyclic stick position. While head acceleration results show a 40-percent reduction in peak deceleration, the potential for fatal injuries still exists. The head injury

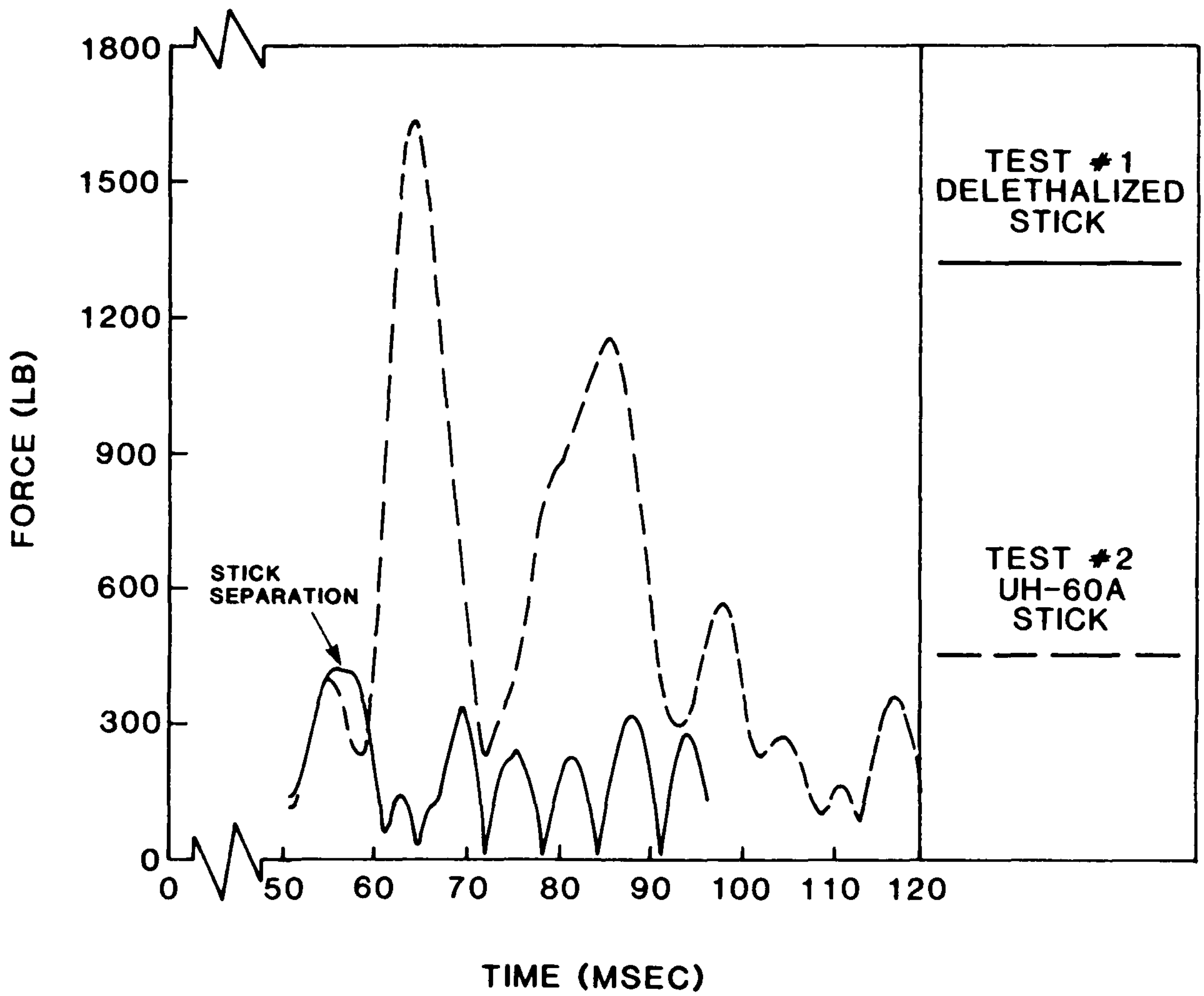


Figure 44. Stick loads - resultants, test nos. 1 and 2.

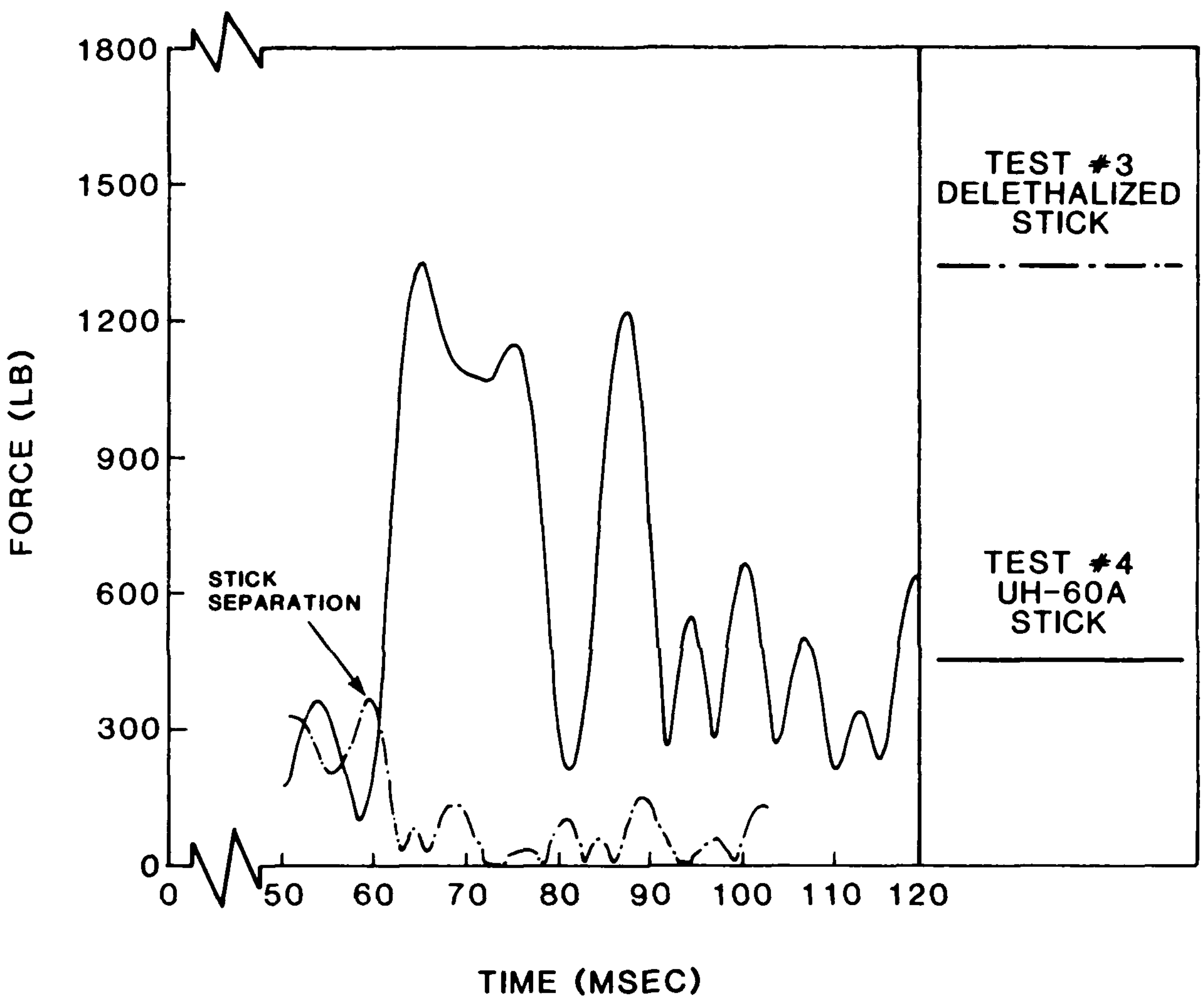


Figure 45. Stick loads - resultants, test nos. 3 and 4.

potential can be evaluated and compared by criteria developed by J. Versace (Reference 8). The criterion for head impact tolerance is given by

$$HIC = \left[(t_2 - t_1) \left(\frac{1}{t_2-t_1} \int_{t_1}^{t_2} a(t)\, dt \right)^{2.5} \right] max.$$

where t_1 and t_2 are the initial and final times (in seconds) during which HIC (head injury criterion) attains a maximum value, and a(t) is the resultant acceleration (in G's) measured at the head center of gravity. Table 7 lists maximum values of HIC for the four drop tests. It has been shown by Reference 10 that an HIC greater than 1,500 would result in a 75-percent probability of brain injury, an HIC between 1,000 and 1,500 would result in a 60-percent chance, an HIC between 500 and 1,000 would result in a 33-percent chance, and an HIC less than 500 would result in an 11-percent chance. Again, the crashworthy cyclic stick has shown an improvement over the currently used stick.

TABLE 7. HEAD INJURY SEVERITY

Test Article	HIC*	Interval (msec)
No. 1 Delethalized Stick	576	49 - 102
No. 2 UH-60A Stick	1066	50 - 96
No. 3 Delethalized Stick	560	48 - 105
No. 4 UH-60A Stick	986	50 - 96

*HIC (Head Injury Criterion), (see Reference 9).

Facial bone fractures due to these impact loads were also considered in the crashworthiness evaluation. To evaluate the injury level of the cyclic stick tests, the relationship between acceleration level and pulse duration on skull fracture was determined from References 5, 7, 8, 9 and 12. The best representation of fracture tolerance appears to be the Wayne State University concussion tolerance curve (Reference 7), which is based on human tolerance level to fracture and is associated with unconsciousness or mild concussions.

Figure 46 depicts the WSU curve relative to data points from this series of tests. The WSU curve applies only to forehead impacts, but the shaded region refers to all other areas of impact. Pulses plotted within this shaded region have been shown to produce some fractures on various facial bones (see Reference 12). For the crashworthy design, there were two events. One being the head-to-stick impact, and the other being the head-to-knee impact. Figure 46 plots both events as primary (head/stick) impact and secondary (head/ knee) impact. Many of the measured impact pulses for the crashworthy stick are very near the tolerance level, but the current stick exceeds this level.

11.3 NECK INJURY

Like the head injury criterion, a similar index has been developed by Patrick (Reference 10) to compare the dynamic reaction of the neck with static strength and to compensate for different head weights of occupants. The neck severity index was defined as

$$NSI = \frac{F_d}{F_s}$$

where F_d is the normalized dynamic load and F_s is the normalized static load. The neck loads were normalized by dividing the measured load by the head weight. Neck reaction data measured in the drop tests are shown and compared to reference data (Reference 11) in Table 8. Reference 11 indicates that a tolerable neck severity index is 2, while 2.5 is evidence of moderate neck injury. Here again, the relative improvement of the crashworthy stick over the UH-60A stick in neck injury reduction is apparent.

In Drop Test nos. 2 and 4, the stick was struck by the dummy in the neck region (see time sequence photographs - Appendix B). With loads approaching 1,000 lb, this was apparently fatal if the tolerance is presumed to be around 100 lb (Reference 8).

Exact correlation of test data with tolerance data is not possible. One particular problem is that there is no data to support a correction for differences in impact areas.

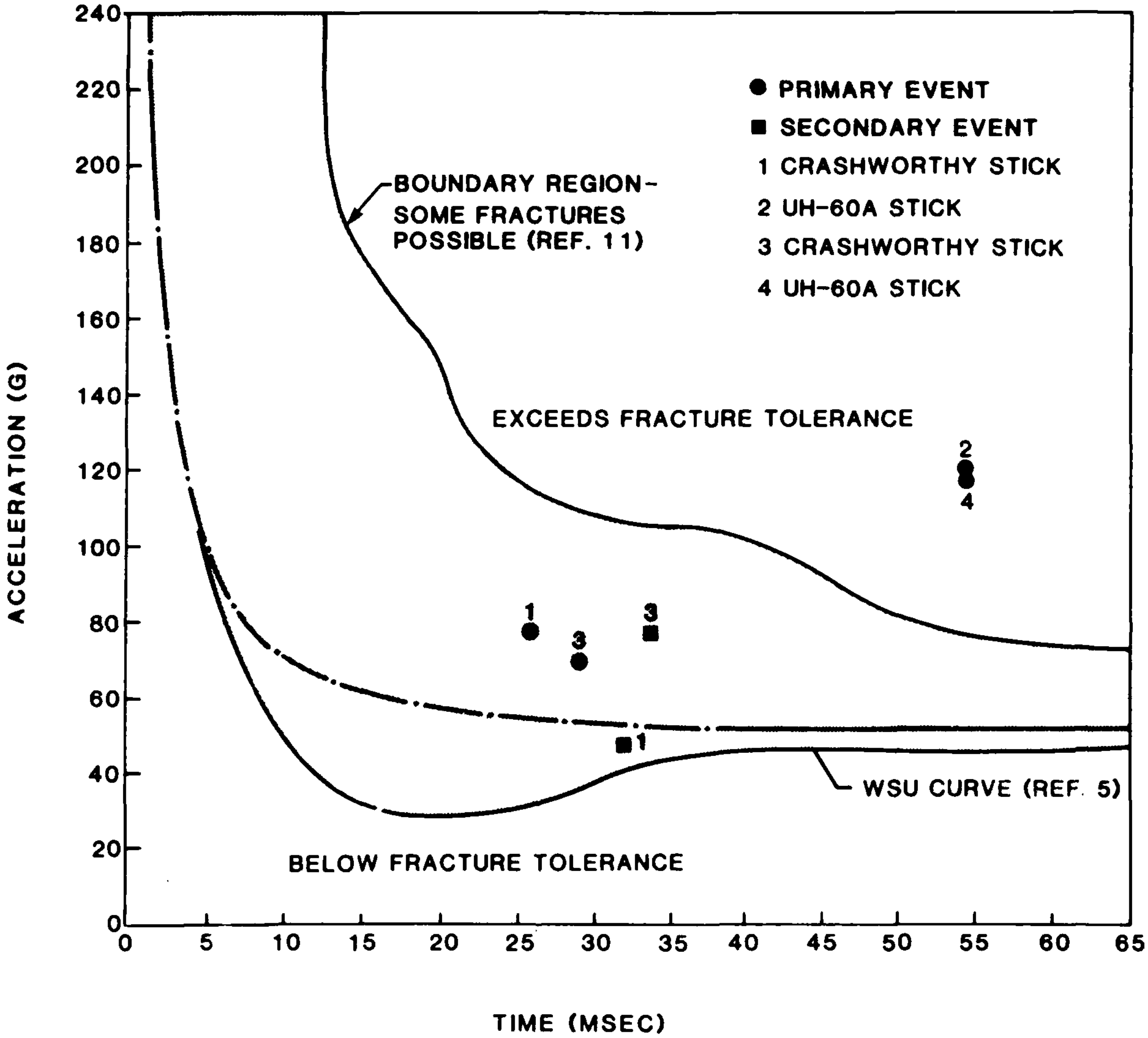


Figure 46. Acceleration - time tolerance curve for skull impact to a hard, flat surface.

TABLE 8. NECK INJURY SEVERITY

	Torque		Shear		Tension	
	In.-Lb	SI*	Lb	SI	Lb	SI
Static Volunteer	210	1.00	190	1.00	255	1.00
Cadaver **	179	1.49	55	.50	42	.30
Cadaver***	305	2.50	61	.55	94	.65
Test No. 1 Delethalized Stick (58 MSEC)	1050	5.00	390	2.05	720	2.82
Test No. 2 UH-60A Stick (60 MSEC)	1908	9.09	900	4.73	1380	5.41
Test No. 3 Delethalized Stick (64 MSEC)	1200	5.71	402	2.12	740	2.90
Test No. 4 UH-60A Stick (72 MSEC)	1750	8.33	800	4.21	1625	6.37

*SI refers to the neck severity index where NSI = F_d/F_s.
**Nonsevere 10-mph simulation.
***Severe 23-mph simulation.

12.0 DISCUSSION OF PROBLEMS

All the objectives of the crashworthy cyclic control stick program were achieved despite certain limitations in design options. The constraint of retaining the production UH-60A grip and the necessity for a vertical adjustment mechanism limit the effectiveness of reducing the inertial weight. In the pendulum tests, the wire load-limiter samples were tested with differing grip weights. For every pound of inertial weight reduced, 30 lb less force is imposed on the occupant (reference Table 4). If the newer grip were used and the vertical adjustment requirement was eliminated, approximately 1.5 lb could be saved. This reduction in inertial weight would equate to a 45-lb reduction in impact force.

There are other factors which limit the effectiveness of the cyclic stick. As discussed in Section 11.0, the velocity of the impactor creates an uncertainty in optimizing the grip pad density. In Table 4, test samples 1 and 2 were tested with differing grip pad densities producing a difference in peak loads. Therefore, the impact force depends to some extent on the grip pad density and to a greater extent on the inertial weight.

The final uncertainty seen in this program, and particularly in the full-scale test results, is determining whether injury would be reduced below tolerable levels. Since insufficient information on facial bone or neck tolerance (for durations greater than 15 msec) was uncovered, one must rely on the relative, rather than absolute, improvements resulting from use of the crashworthy stick. The head and neck injury criterion shows that the new cyclic control stick reduced the severity of the impact by one-half, as compared to the current UH-60A stick.

13.0 CONCLUSIONS AND RECOMMENDATIONS

In the design phase (Task I), the inertial weight was reduced to the practical minimum. Four inches of vertical adjustment are provided. The crashworthy stick is designed to accept the baseline grip (UH-60A) and with an adapter, will accept the newer grip. As much space is provided in the new stick as in the current UH-60A stick for the specific minimum of 36 electrical conductors inside the adjusting upper tube below the grip.

The operational requirements of Reference 4 were met in Task II. The crashworthy stick samples supported the required loads in all directions with no permanent deformations.

The function of the crashworthy stick design was demonstrated by controlled dynamic testing, using a pendulum impactor. The expected dynamic performance was achieved. Based solely on the pendulum tests, the tab load-limiter design was eliminated because of somewhat higher loads as compared to the wire load-limiter design. The wire load-limiter design was chosen as the best performer and was used in the next testing phase.

In Task III (full-scale dynamic testing), the crashworthy stick functioned as expected, but results showed higher than expected impact loads. These tests showed the reduction in injury severity was significant for the new stick design.

Because of the success of the program in reducing the lethality of the cyclic control stick, based on relative merits, it is recommended that the crashworthy cyclic stick design be flight tested. Following a successful flight test, a production run and retrofit into the applicable aircraft is advised. The performance observed in the comparative tests suggests that utilization of the delethalized stick would at least reduce the frequency and severity of injury imposed by occupant/stick impact.

For a more quantitative evaluation of the effectiveness of the delethalized stick, further testing is needed. Either further impact data for the human face must be developed or further tests must be performed with the crashworthy cyclic stick using human cadavers. Whatever the outcome of such tests, it is believed that the new design tested is as good as it can be, given the constraints. Additional tests would better define lethality of the stick and perhaps further justify its use. No further design improvement is expected except for, perhaps, changes in foam pad stiffness.

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APPENDIX A
RETROFIT INSTRUCTIONS

RETROFIT PROCEDURE - IN THE FIELD

REMOVAL OF UH-60A STICK (Refer to Figure A-1)

1. Remove boot.

2. Remove SS27576-4-14 bolt and disconnect control rod from cyclic stick lever.

3. Remove SS27576-5-10 pivot bolt and disconnect cyclic stick from housing.

4. Disconnect wire harness from airframe connector, remove cyclic stick from aircraft.

5. Remove NAS 1304-23 bolt from socket and stick connection; detach tube from socket.

INSTALLATION OF NEW STICK IN THE AIRCRAFT (Refer to Figures A-1 and A-3)

1. Install crashworthy stick into socket with new 1305-23 bolt.

2. Using 0.250-in.-diameter reamed holes (in the socket) and 0.125-in.- diameter pilot holes (in the stick) as a guide, drill and ream for NAS 1305-23 bolt. Torque bolt 120 to 160 in.-lb.

NOTE: To ensure a good tight fit, a 5/16 bolt size is reamed to replace the 1/4 bolt.

3. Install stick assembly into pivot fitting. Reuse hardware previously removed, except use new cotter pin.

4. Connect electrical plug to airframe receptacle.

5. Reconnect control rod to cyclic stick lever. Reuse hardware, except use new cotter pin.

6. Reinstall boot.

NOTE: It is mandatory that the SS impedance type bolts are reinstalled in their original locations, no substitutions are allowed. In order that the correct torque can be applied, it is essential that the original washer configuration is used.

CAUTION: A down load of over 120 lb applied to the grip will cause separation of the stick joint.

RETROFIT PROCEDURE - AT THE DEPOT

REMOVAL OF UH-60A GRIP FROM OLD STICK (Refer to Figure A-2)

1. Refer to 70400-01222 for wire/pin connection details and using suitable tool, disconnect connector from wire harness.

2. Remove NAS 1303-21 bolt from stick and grip, and remove grip from stick tube, pulling wire harness through tube.

INSTALLATION OF GRIP PAD (Refer to Figure A-3)

1. Prepare grip surface by flame treatment.

2. Bond grip pad (P/N SK11075-1) to top of grip with 3M P/N 2216 adhesive (gray color).

INSTALLATION OF NEW GRIP ON CRASHWORTHY STICK (Refer to Figure A-3)

1. Install new grip assembly on the crashworthy cyclic stick (P/N SK11074-1) as follows: Push wire bundle through tube (one bundle on each side of bolt bushing in tube), capture wire bundle at lower end of tube and pull through exit hole. Ensure that the grip fits correctly onto the stick tube, reinstall NAS 1303-21 bolt. Torque bolt 30 to 40 in.-lb.

2. Using suitable tool, refit electrical connector plug to wire harness, in accordance with Drawing No. 70400-01222.

3. Verify electrical connections. Test equipment at Sikorsky Aircraft may be used.

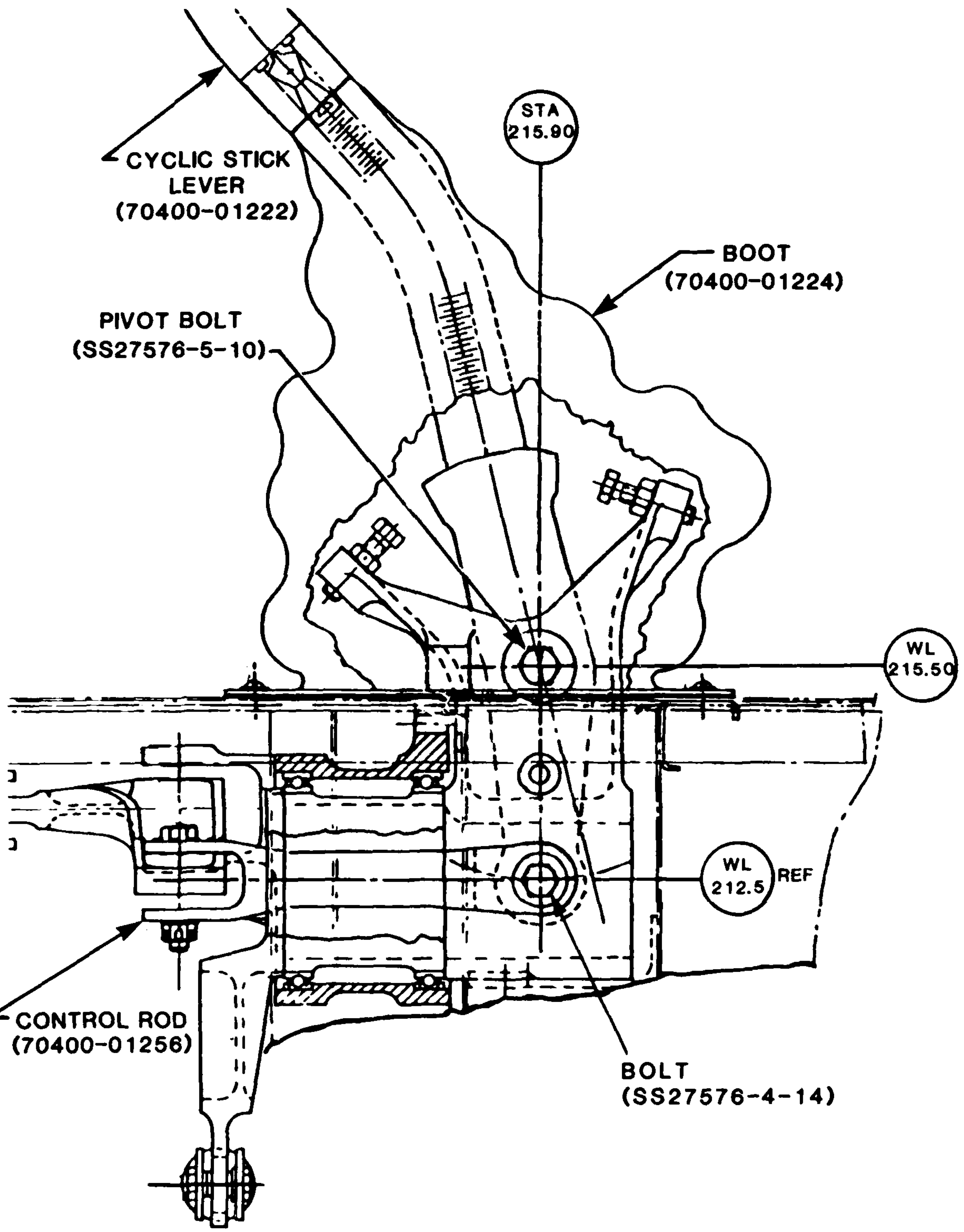


Figure A-1. Stick removal/installation.

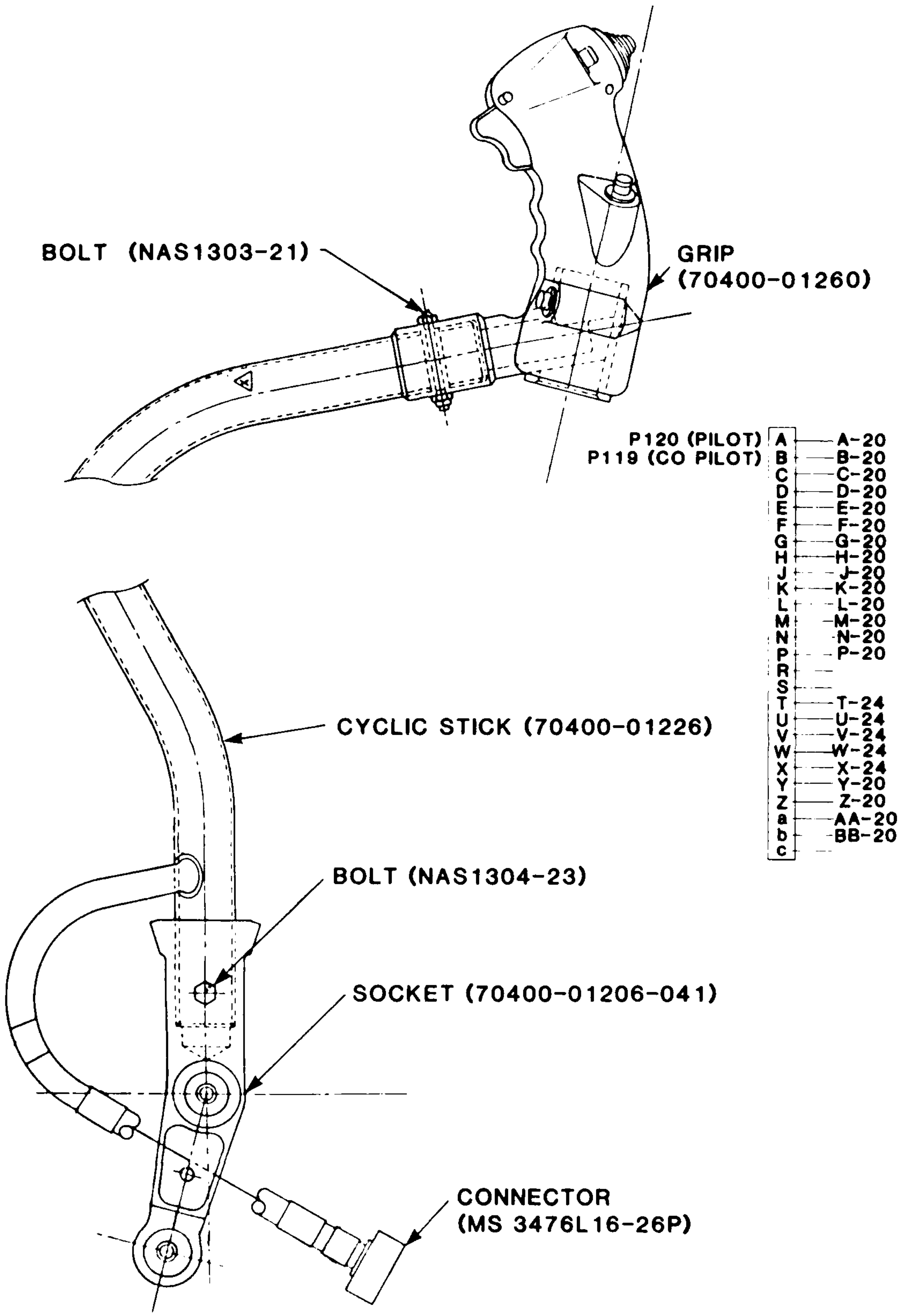


Figure A-2. Cyclic stick assembly.

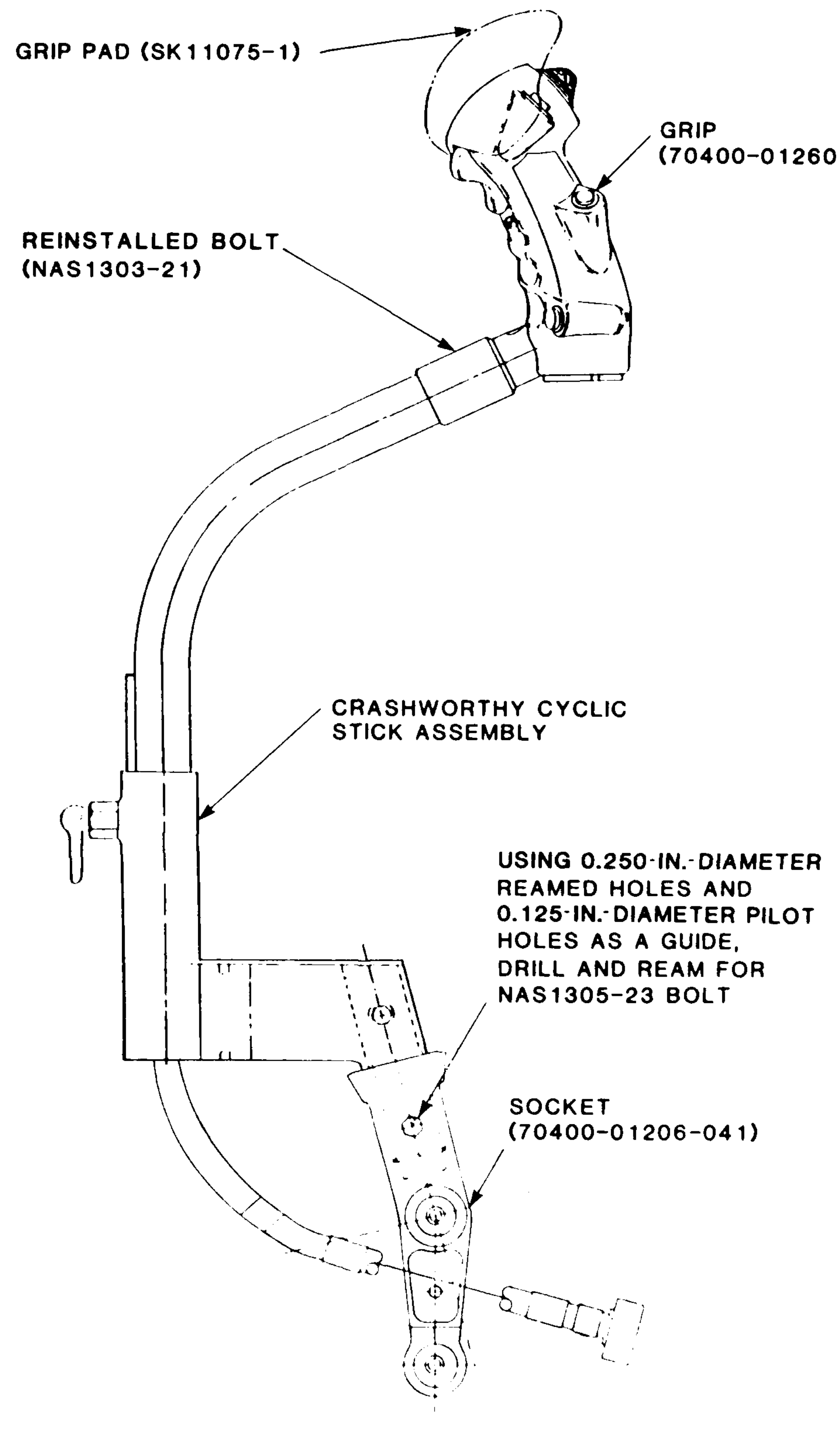
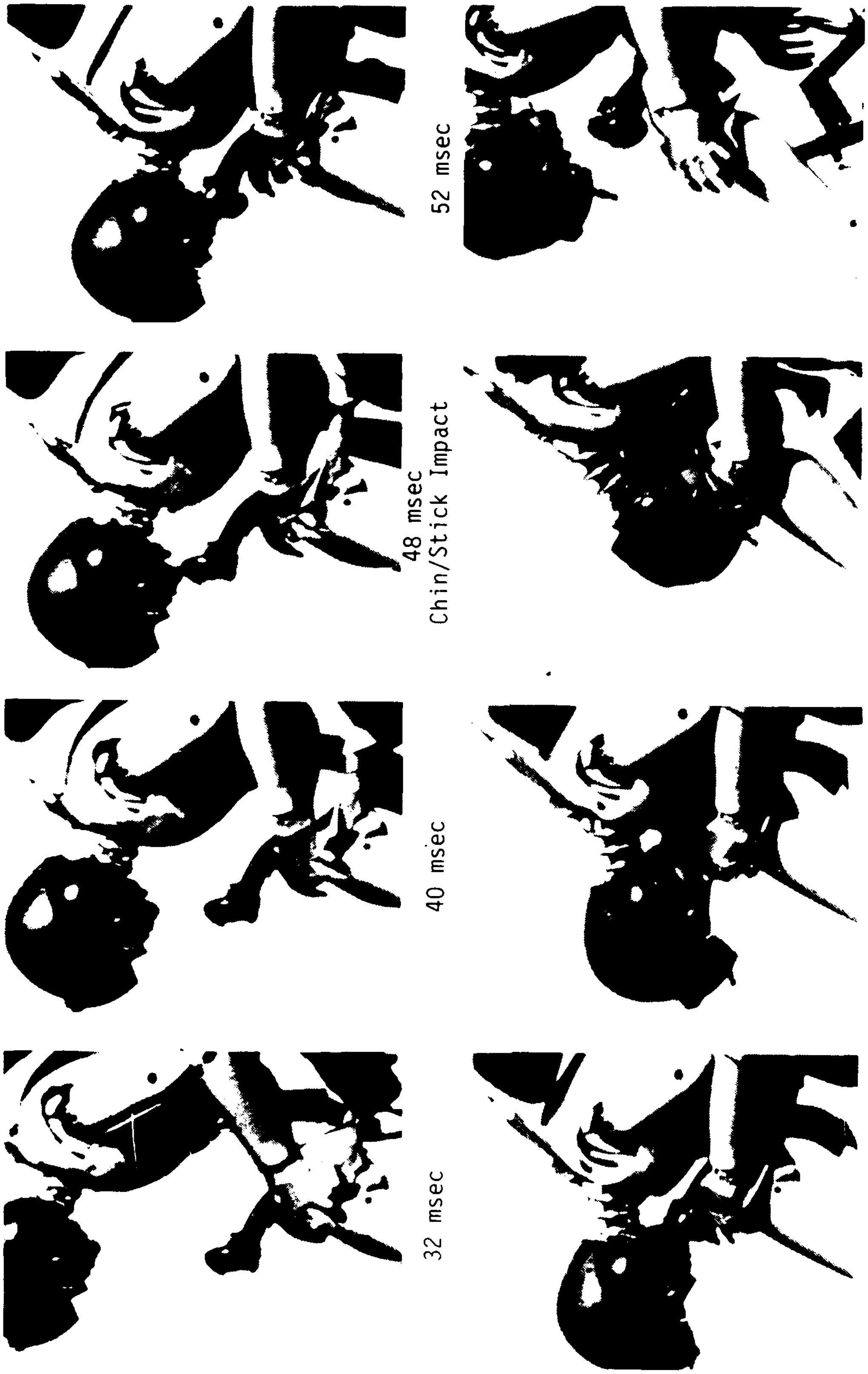


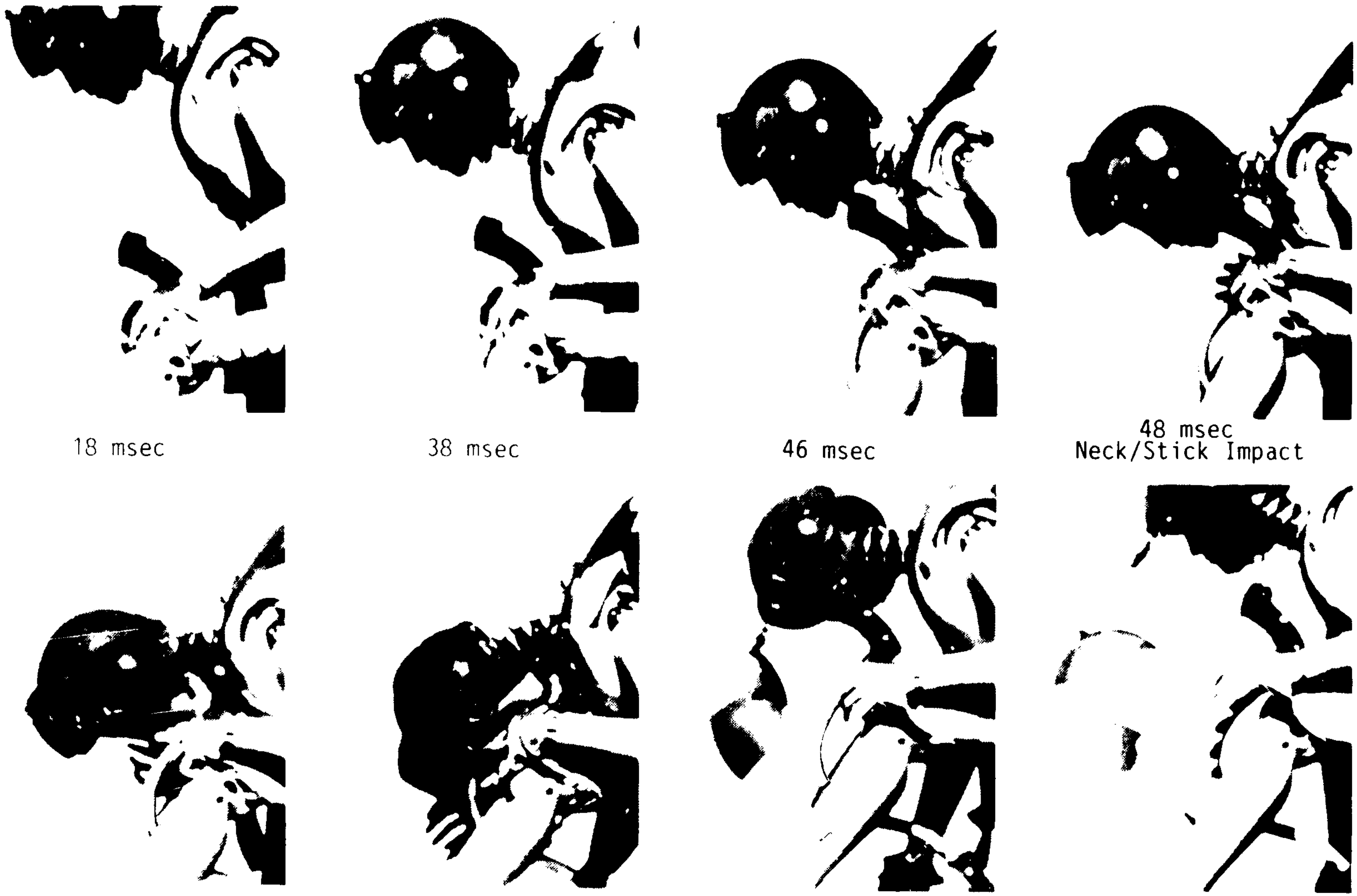
Figure A-3. Installation of crashworthy cyclic stick.

TIME SEQUENCE PHOTOGRAPHS OF THE DYNAMIC TESTS



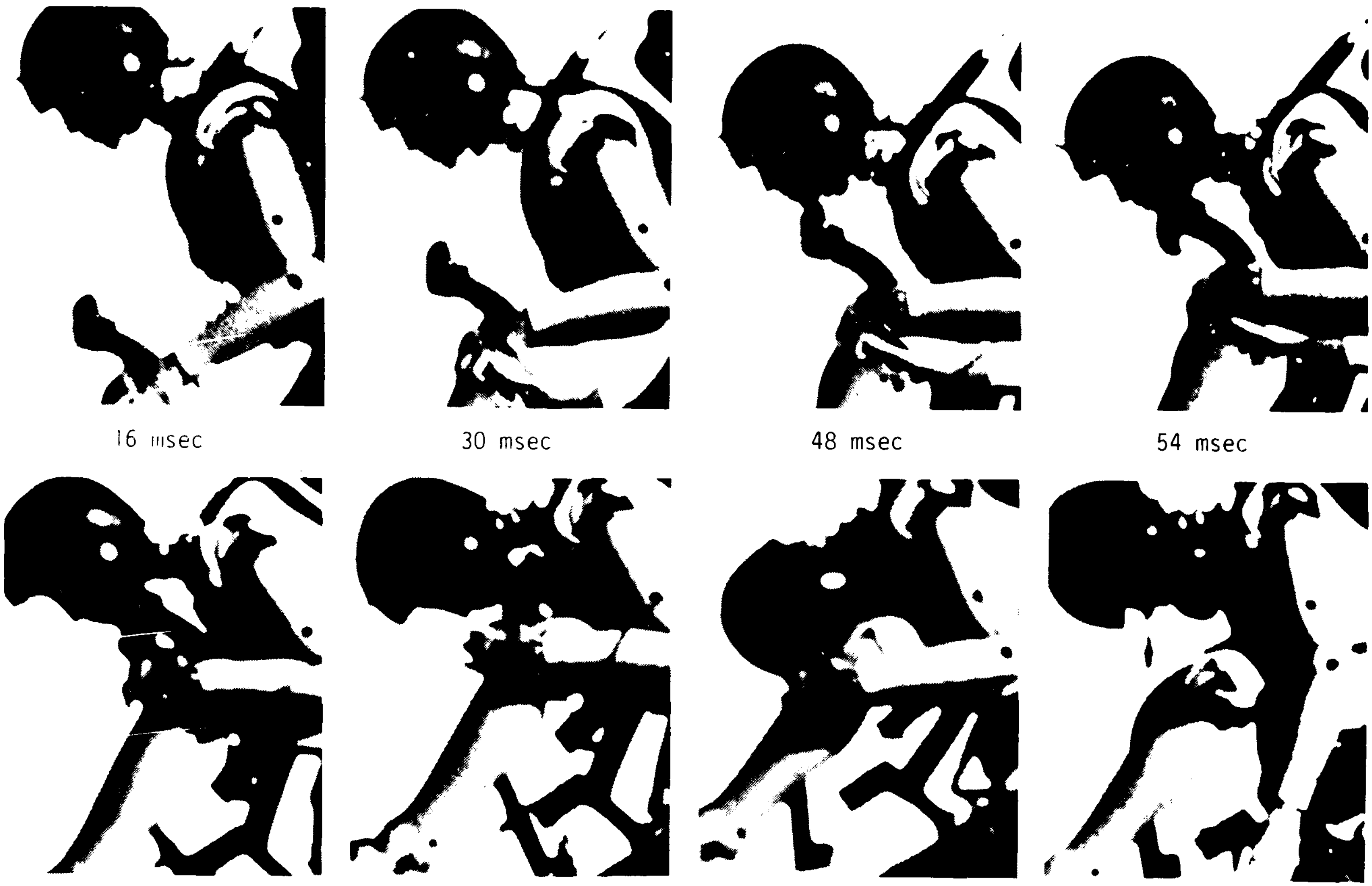
Durations refer to time after cage impact

Figure B-1. Time sequence frames for test no. 1.



Durations refer to time after cage impact

Figure B-2. Time sequence frames for test no. 2.

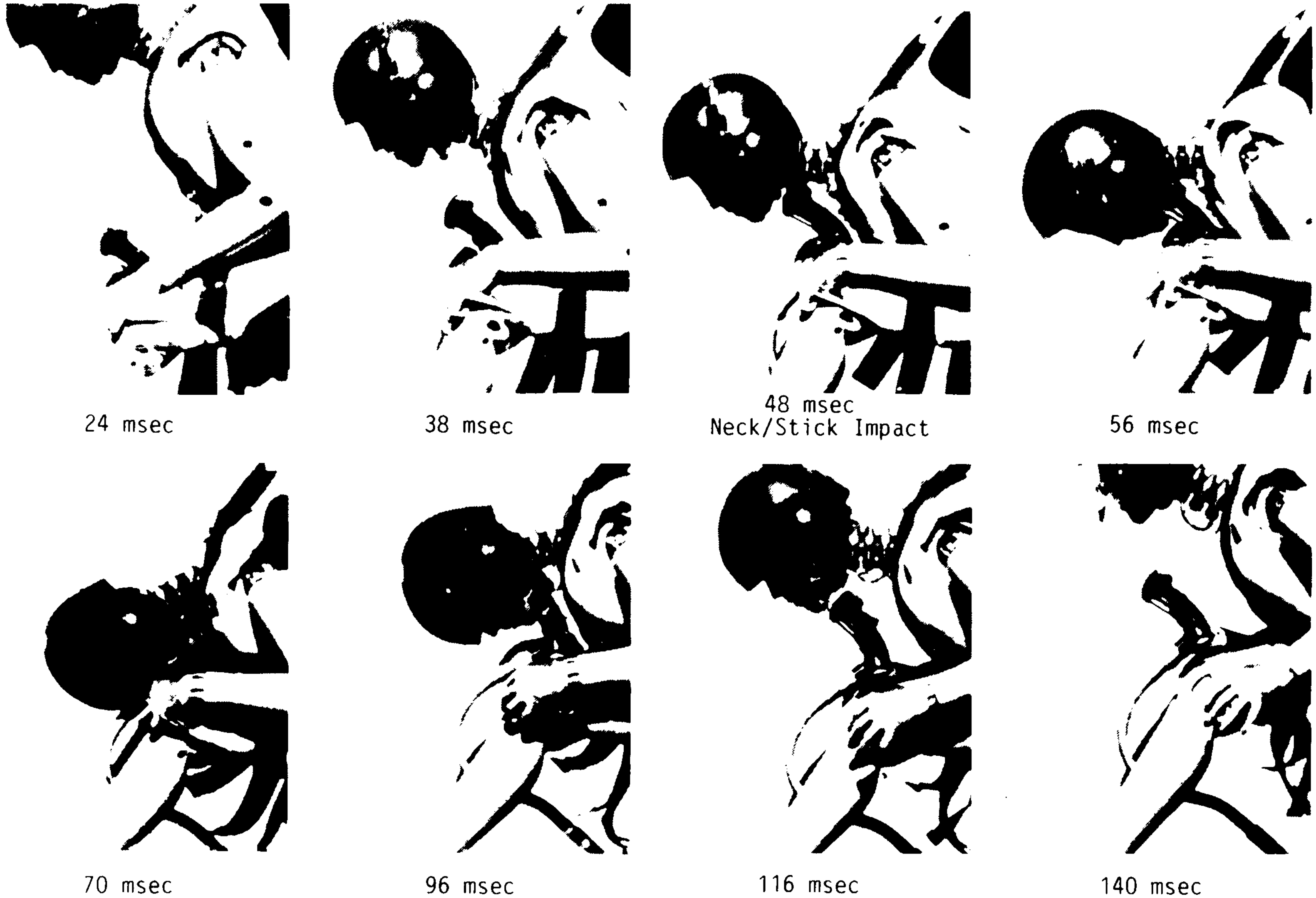


16 msec 30 msec 48 msec 54 msec

60 msec 68 msec 86 msec 144 msec

Durations refer to time after cage impact

Figure B-3. Time sequence frames for test no. 3.



Durations refer to time after cage impact

Figure B-4. Time sequence frames for test no. 4.

APPENDIX C
FORWARD, LATERAL, AND DOWNWARD
LOAD COMPONENTS FROM THE STICK LOAD CELLS

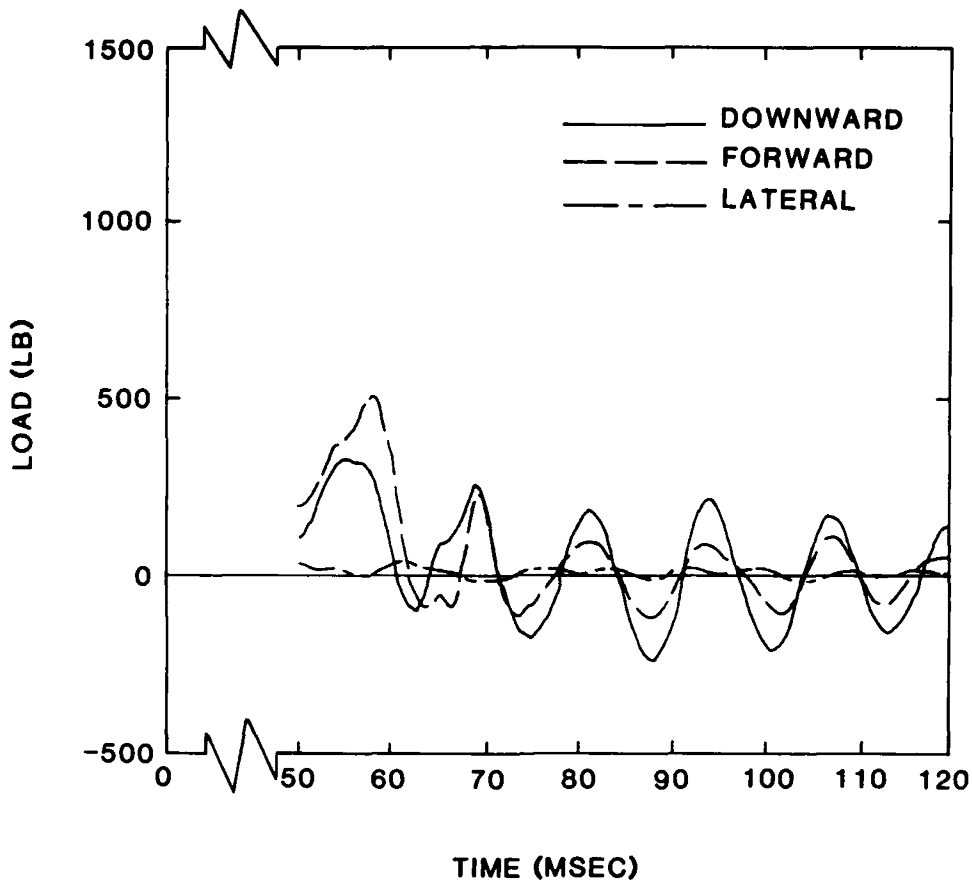


Figure C-1. Cyclic stick component loads, test no. 1.

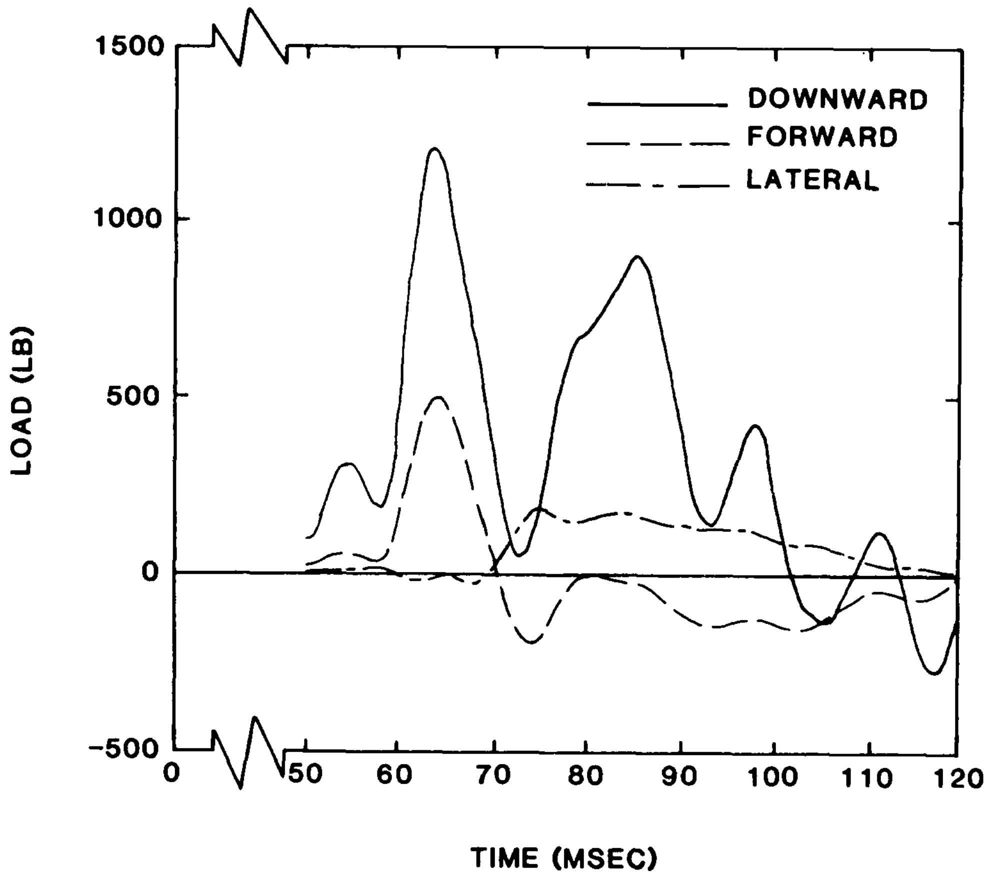


Figure C-2. Cyclic stick component loads, test no. 2.

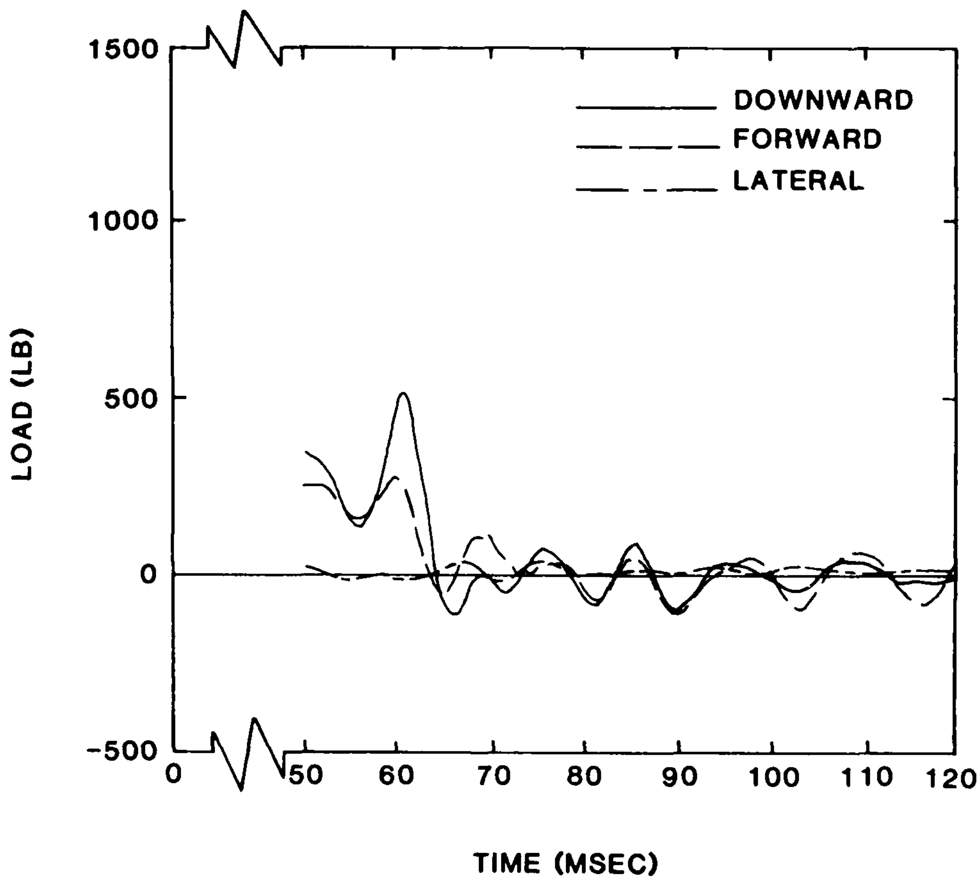


Figure C-3. Cyclic stick component loads, test no. 3.

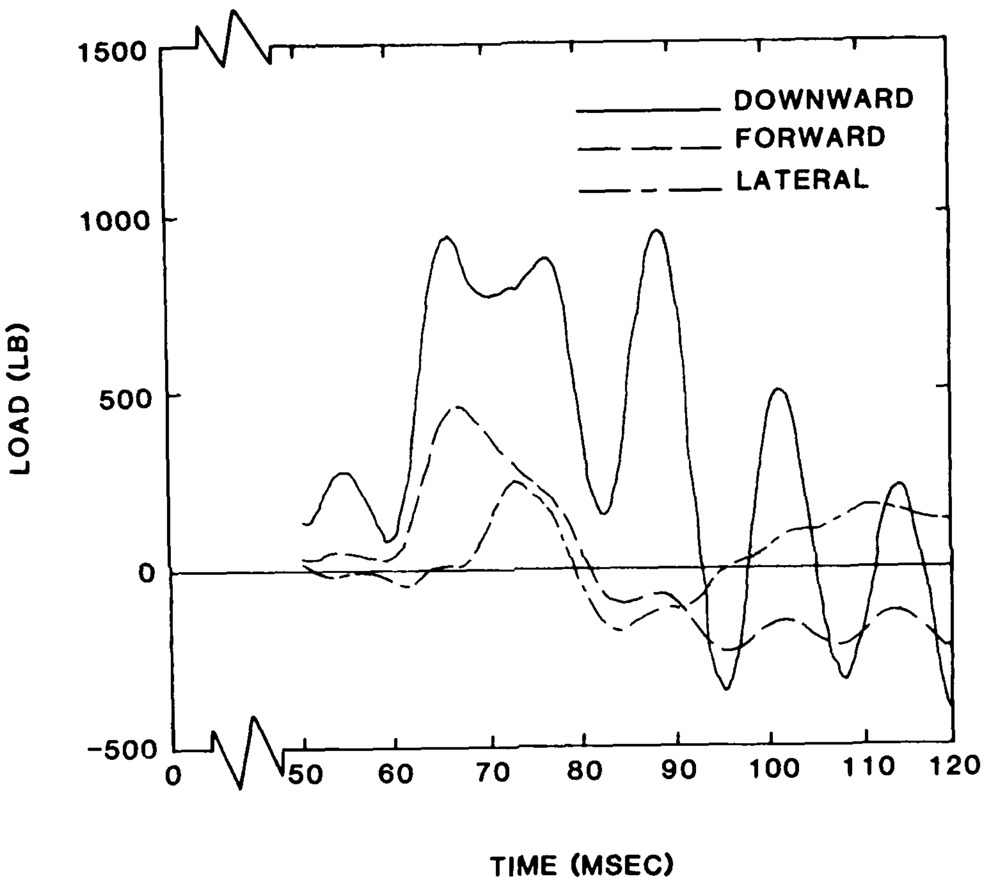


Figure C-4. Cyclic stick component loads, test no. 4.

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